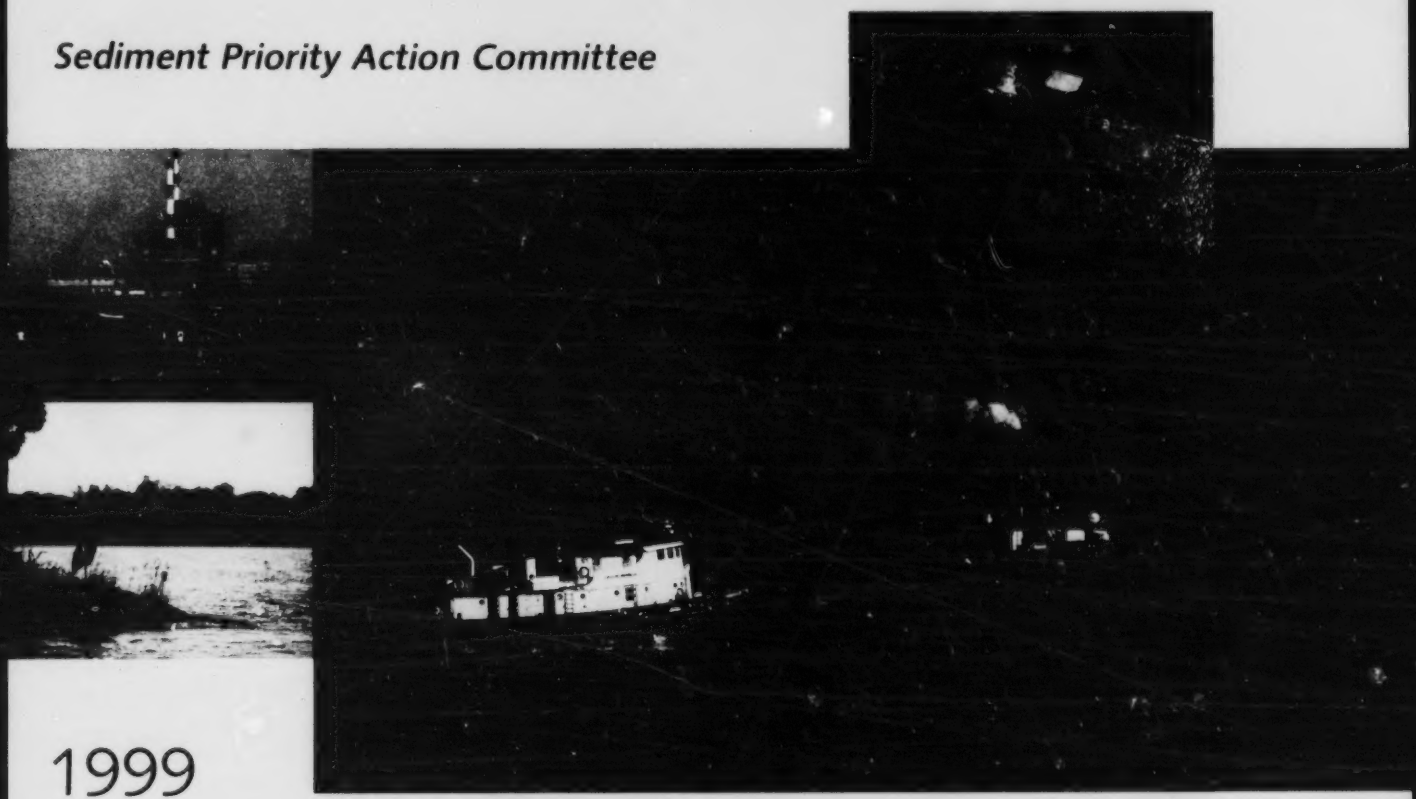
Deciding When to Intervene

Data Interpretation Tools for Making Sediment Management Decisions Beyond Source Control

Sediment Priority Action Committee



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Based on a Workshop Held at the
Great Lakes Institute for Environmental Research
***University of Windsor**, December 1-2, 1998*

Great Lakes
Water Quality
Board

Report to
the International
Joint Commission

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Data Interpretation Tools for Making Sediment Management Decisions Beyond Source Control

Based on a Workshop to Evaluate Data Interpretation Tools held at the Great Lakes Institute for Environmental Research, University of Windsor, December 1-2, 1998

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Sediment Priority Action Committee
Great Lakes Water Quality Board

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PREFACE

The International Joint Commission (IJC) has identified contaminated sediment as a program priority. During the 1997-1999 biennial cycle, the IJC directed the Great Lakes Water Quality Board (WQB) and its Sediment Priority Action Committee (SedPAC) to develop guidance for making decisions regarding management of contaminated sediment and to compile and disseminate information on benefits of sediment remediation.

Sediment management experts from throughout the Great Lakes Basin and beyond met for a workshop in Windsor, Ontario on December 1-2, 1998 (see Appendices 1 and 2). They examined and exchanged tools that are used to interpret environmental data to deduce scientifically whether or not to take sediment management actions beyond source control.

Please note that this report is not a manual for sediment assessment or selection of remedial technologies, compilations of which are available from federal, provincial, and state agencies. Other elements of sediment management decision-making such as socio-economic factors are not considered here, but their importance is noted within this report.

This report of SedPAC synthesizes and interprets the scientific methodologies and management experiences presented at the workshop in a fashion which provides clear, timely advice on the use of scientific data interpretation tools used to make a sediment management decision. It is intended to disseminate methodologies for evaluating the degree to which an intervention for sediment cleanup is ecologically compelling.

I. EXECUTIVE SUMMARY

There is a consensus among diverse sectors in the Great Lakes Basin (e.g., government, industry, non-governmental organizations, Remedial Action Plan groups) that contaminated sediment is an important element leading to many of the impairments to beneficial uses of the Great Lakes. All 42 Great Lakes Areas of Concern have contaminated sediment based on application of chemical guidelines. This universal obstacle to environmental recovery in Areas of Concern can potentially pose a challenge to restoring 11 of the 14 beneficial use impairments identified in the Great Lakes Water Quality Agreement (SedPAC 1997).

For Remedial Action Plans (RAPs), sediment management decisions need to be made bearing in mind the relationship between contaminated sediment and restoration of beneficial uses. This goes far beyond setting a numerical chemical cleanup criteria, as these are not based on the need to fully restore beneficial uses. What is needed is a pragmatic decision-making framework that leads to the selection of ecosystem and cost-effective options for management of contaminated sediment.

The Water Quality Board (WQB) has called for a step-wise and incremental approach to management of contaminated sediment and restoration of beneficial uses (SedPAC 1997). Sediment remediation, removal of a mass of contaminants, and reduction of risk are important indicators of incremental progress. The ultimate success of sediment management activities will be judged upon restoration of beneficial uses (e.g., elimination of fish consumption advisories, restoration of fish and wildlife populations, restoration of benthos).

Sediment cleanup that results in a mass of contaminants being removed from the ecosystem reduces risks to fish, wildlife, and humans. This type of cleanup represents incremental progress towards the ultimate success of managing sediment: restoring beneficial uses.

Bioassessment frameworks have evolved substantially recently, and in many cases large data sets have the required elements for developing a sediment management strategy. Equally important to the collection of data, however, is that sufficient attention be placed on thorough and comprehensive interpretation of the data. By employing scientifically sound methods of data interpretation, the information from an intensive sediment assessment can finally be integrated to make a decision to intervene (i.e., remediate contaminated sediment) or pursue source control and natural recovery as the preferred remedial option.

SedPAC's primary intent with this document is to share advances in data interpretation tools regarding sediment management decision-making with RAP practitioners. Presently, a great deal of data have been collected on the physical, chemical, and biological elements that modify contaminant bioavailability and ecological effects. The literature contained herein and cited below can help guide RAP practitioners through a transparent use restoration decision-making process.

In addition to this review of data interpretation tools, SedPAC recognizes that the International Joint Commission (IJC) can offer more assistance in the efforts to overcome obstacles to sediment management. Specifically, SedPAC recommends:

- **that the Commission recommends to the Parties and Jurisdictions that they develop and reach agreement on methods or programs to predict and measure successful ecological recovery in Areas of Concern (e.g., ecological benefit forecasting, monitoring and surveillance programs to measure use restoration); and**

- **that the Commission recommends to the Parties and Jurisdictions that they establish procedures for consistent data collection and interpretation across Areas of Concern, recognizing the importance of site specificity in applying methodologies and tools.**

The Commissioners also have an important role to fulfill in overcoming obstacles to sediment management for beneficial use restoration. SedPAC recommends that Commissioners:

- **develop and implement an IJC public outreach strategy to help make contaminated sediment management a priority throughout the basin.**

SedPAC notes that there are currently few, if any, simple or proven methods to predict recovery of use impairments based on sediment cleanup. More research is needed to quantify the relationships between contaminated sediment and known use impairments. The concept of ecological benefit forecasting (i.e., predicting ecological benefits and restoration of beneficial uses) is an important management need, which if accomplished, would be a substantial step forward.

Finally, deciding when to intervene is embedded with multiple elements. Data interpretation tools and techniques are a central element in developing the sediment management strategy. This report is one in a series that will explore a number of aspects affecting sediment management. Other aspects involve what is and is not known about linking sediment cleanup to ecological recovery and restoration of beneficial uses, as well as economic benefits that may accrue from effective management of contaminated sediment.

II. INTRODUCTION

There is a consensus among diverse sectors in the Great Lakes Basin (e.g., government, industry, non-governmental organizations, RAP groups) that contaminated sediment is an important element leading to many of the impairments to beneficial uses of the Great Lakes. All 42 Great Lakes Areas of Concern have contaminated sediment based on application of chemical guidelines. This universal obstacle to environmental recovery in Areas of Concern can potentially pose a challenge to restoring 11 of the 14 beneficial use impairments identified in the Great Lakes Water Quality Agreement (SedPAC 1997).

These findings were revealed by SedPAC, which was established in 1996 by the WQB of the IJC. SedPACs' mandate is to examine the magnitude of the contaminated sediment problem in Great Lakes Areas of Concern and provide advice on how to overcome obstacles to sediment management. The challenges to progress in sediment remediation include, but are not limited to: the inability to define the extent of the problem, developing a strategy to address the problem, and defining the cleanup standard (SedPAC 1997).

By way of illustration, in many Areas of Concern, technical and community team members are struggling to reach decisions on whether or not environmental or ecological harm resulting from the presence of contaminated sediment is such that intervention is needed. For RAPs, sediment management decisions need to be made bearing in mind the relationship between contaminated sediment and restoration of beneficial uses. This goes far beyond setting a numerical chemical cleanup criteria, as these are not generally based on the need to fully restore beneficial uses.

In this light, guidance is needed on the breadth of information that should be collected and how the information or data are interpreted. No comprehensive and ecologically-based methods are commonly available that illustrate how to evaluate and integrate chemical, eco-toxicological, and ecological results in an objective, pre-defined manner to arrive at a decision surrounding the severity of sediment contamination.

To address this need, one of several initiatives of SedPAC is to explore and exchange methods to interpret sediment assessment data and formulate decisions on whether to take action beyond source control. Apart from source control, the required levels and rates for cleanup to restore uses are far from obvious, and in some cases, appear unknown. While decisions to clean up contaminated sediment depend on a large number of variables (e.g., economics, regulations, technology), sound science must be one important element. However, scientific frameworks for evaluating the ecological significance of contaminants in sediment are either lacking or not widely used or communicated. Local decision-making has been assisted by the proliferation and adoption of numerous bioassessment techniques. Such decision-making, however, is hampered by lack of guidance on defining quantitatively acceptable or unacceptable results or conditions. To add a further layer of difficulty, there are few widely-accepted methods to integrate the large number of environmental measurements that result from a comprehensive sediment assessment.

EXCERPTS FROM ANNEX 14

1. Objectives:

...identify the nature and extent of sediment pollution of the Great Lakes System

...develop methods to evaluate...the impact of polluted sediments on the Great Lakes System

2. Research and Studies:

(a) General

...exchange information relating to the mapping, assessment and management of contaminated sediments

(b)Surveillance Programs

(ii)...review practices in both countries regarding the classification of contaminated sediments and establish compatible criteria for the classification of sediment quality

(iv)...develop a standard approach and agreed procedures for the management of contaminated sediments by December 31, 1988

What is needed is a pragmatic decision-making framework that leads to the selection of ecosystem-and-cost-effective options for management of contaminated sediment. As SedPAC (1997) has noted:

> "It is imperative that any active intervention for sediment management beyond source control be aimed at use restoration, based on the weight of evidence of the biological data that demonstrates action other than natural recovery is necessary."

Recently, the Parties and the IJC have been cooperating to develop joint decision-making tools that will allow for consistent, comprehensive, ecologically-based approaches to sediment management. This is consistent with the needs stated in Annex 14 of the Great Lakes Water Quality Agreement.

In December 1998, sediment management experts from throughout the Great Lakes Basin and beyond met in Windsor, Ontario to exchange and examine the tools that are used as a means for arriving at a decision regarding whether or not to take action beyond source control. This report synthesizes the scientific methodologies and management experiences brought together by the participants. The intent is to provide RAP decision-makers with advice on methods for resolving those considerations, in order to finalize site-specific sediment management strategies.

III. SYNTHESIS AND FINDINGS

A central tenet to rehabilitating sediment quality and renewing ecosystem health is that control of contaminants at their source remains the primary imperative for action. It can only be through the cessation of inputs of contaminants from sources that other sediment management actions such as sediment removal can be economically viable, ecologically successful, and sustainable.

The Imperative: Restoring Beneficial Uses

According to Annex 2 of the Great Lakes Water Quality Agreement, the purpose of RAPs is the restoration of beneficial uses. Contaminated sediment potentially poses a challenge in restoring 11 of the 14 beneficial use impairments identified in the Great Lakes Water Quality Agreement (SedPAC 1997). Therefore, decisions regarding sediment management actions in Areas of Concern should be tempered and driven by the goal of restoring beneficial uses.

Decisions regarding sediment management actions in Areas of Concern should be tempered and driven by the goal of restoring beneficial uses.

Indicators are measurable features which provide communities, scientists, and resource managers with useful information on the state of the ecosystem, environmental quality or trends, and the status of programs and activities directed at rehabilitating the Great Lakes ecosystem. Indicators measure progress toward community-based and/or government-driven management goals. If the goal of RAPs is restoration of beneficial uses, then indicators of a successful sediment management strategy should include progress toward restoration of beneficial uses.

In general, sediment management can be viewed as either activities or outcomes. Sediment management activity indicators include issuance of permits by governments, control of contaminants at their source, and sediment remediation. Outcome indicators can include environmental responses such as changes in fish and wildlife populations and human health risk (Table 1). Therefore, sediment management can and should be evaluated against a spectrum of indicators ranging from programmatic activities to ecosystem outcomes.

It must be recognized that there are considerable interrelationships among sediment management indicators and use impairments (Table 1). There can also be a temporal factor in restoring certain use impairments. For example, a sediment management activity like dredging and disposal will have an immediate impact on sediment chemistry. However, the effect of this same sediment management activity on liver tumors in fish and consumption advisories may not occur for several to many years later. Such interrelationships and temporal sequencing must be understood and considered in the assessment of sediment quality, data interpretation, and final sediment management decisions.

Table 1. The interrelationships among sediment management outcome indicators and use impairments as defined in the Great Lakes Water Quality Agreement (GLWQA)

INDICATOR OR MEASUREMENT	USE IMPAIRMENTS MOST CLEARLY ADDRESSED (As defined in Annex 2 of GLWQA)	RELATIVE TIME SCALE* FOR RESTORATION OF BENEFICIAL USES
Improvements in sediment chemistry	• Restrictions on dredging activities, added costs to agriculture and industry, degradation of aesthetics, eutrophication or undesirable algae	• Short-term
	• Degradation of phytoplankton or zooplankton populations	• Short-term to intermediate
	• Degradation of benthos, loss of fish and wildlife habitat	• Intermediate to long-term
Improvements in toxicity in sediment bioassays (invertebrates)	• Eutrophication or undesirable algae	• Short-term
	• Degradation of phytoplankton or zooplankton populations	• Short-term to intermediate
	• Degradation of benthos, loss of fish and wildlife habitat	• Intermediate to long-term
Improvements in benthic invertebrate community structure	• Degradation of benthos, loss of fish and wildlife habitat, degradation of fish and wildlife populations	• Intermediate to long-term
Decline in bioaccumulation and biomagnification	• Loss of fish and wildlife habitat, degradation of benthos, fish tumors or other deformities, bird or animal deformities or reproductive problems, restrictions on fish and wildlife consumption	• Intermediate
	• Degradation of fish and wildlife populations	• Intermediate to long-term
Improvements in vertebrate populations and communities	• Eutrophication or undesirable algae, fish tumors or other deformities, bird or animal deformities or reproductive problems	• Short-term to intermediate
	• Loss of fish and wildlife habitat, degradation of fish and wildlife populations	• Intermediate to long-term
Decline in risk to human health	• Restrictions on fish and wildlife consumption	• Intermediate to long-term

* Relative time scale: Depending on the degree of degradation, even a short-term time scale can span months to years. Subsequent response times would then be relative to achieving the earlier indicators of improved ecological conditions.

In general, the highest order and most important indicators in the context of restoring beneficial uses are seen as the ones that represent ecosystem outcomes. The WQB has called for a step-wise and incremental approach to management of contaminated sediment and restoration of beneficial uses (SedPAC 1997). Sediment remediation, removal of a mass of contaminants, and reduction of risk are important indicators of incremental progress. The ultimate success of sediment management activities will be judged upon restoration of beneficial uses (e.g., elimination of fish consumption advisories, restoration of fish and wildlife populations, restoration of benthos).

It is generally accepted that progress in sediment management should be measured by a broad spectrum of indicators. However, it must be recognized that there are considerable interrelationships and temporal complexities among sediment management indicators and the 11 beneficial use impairments potentially affected by contaminated sediment (Table 1). As a result, it is easy to understand why there is no simple approach to applying data interpretation tools to make sediment management decisions.

Considerable work has been undertaken to identify beneficial use impairments in Areas of Concern. This extensive effort to identify the status and cause of impairments provides a good foundation to guide sediment management decisions. To rehabilitate an Area of Concern, linkages between contaminated sediment and known use impairments must be considered (Figure 1). In many cases, the information needed to make the connections has been collected by assessing chemistry, benthic community structure and composition, laboratory toxicity, contaminant bioaccumulation/biomagnification, and sediment/site stability.

To rehabilitate an Area of Concern, linkages between contaminated sediment and known use impairments must be considered.

If contaminated sediment is not causing or contributing to any use impairments, and site stability is clearly known to be high, then regardless of sediment chemistry, no sediment management actions are recommended beyond routine monitoring (and pollution prevention). However, if the data link contaminated sediment to one or more use impairments, and site stability cannot be ensured, then it is recommended that an intensive assessment of the quantitative relationships between contaminated sediment and use impairments be undertaken.

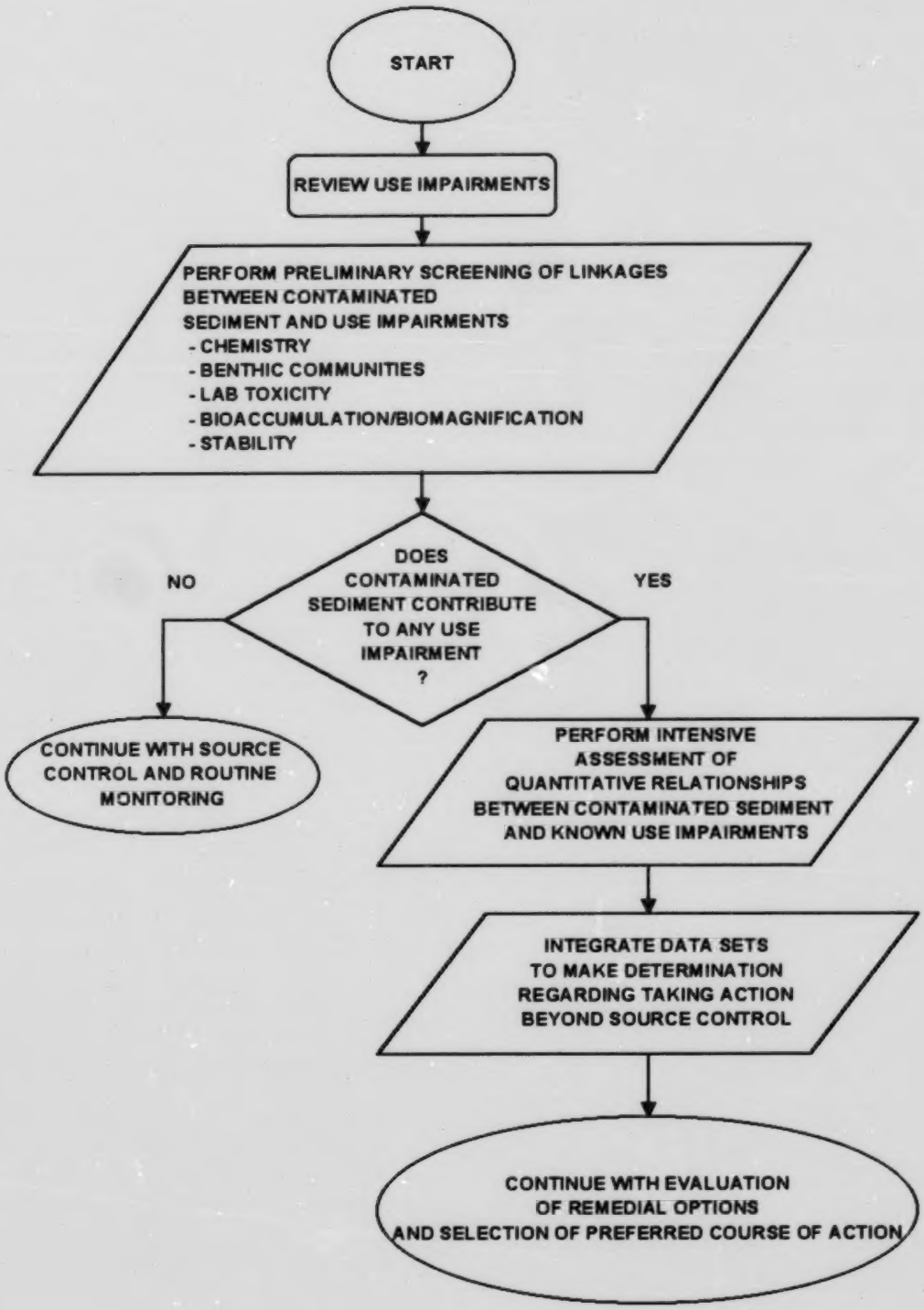
START
REVIEW USE IMPAIRMENTS
PERFORM PRELIMINARY SCREENING OF LINKAGES BETWEEN CONTAMINATED SEDIMENT AND USE IMPAIRMENTS
- CHEMISTRY
- BENTHIC COMMUNITIES
- LAB TOXICITY
- BIOACCUMULATION/BIOMAGNIFICATION
- STABILITY
DOES CONTAMINATED SEDIMENT CONTRIBUTE TO ANY USE IMPAIRMENT ?
NO
YES
CONTINUE WITH SOURCE CONTROL AND ROUTINE MONITORING
PERFORM INTENSIVE ASSESSMENT OF QUANTITATIVE RELATIONSHIPS BETWEEN CONTAMINATED SEDIMENT AND KNOWN USE IMPAIRMENTS
INTEGRATE DATA SETS TO MAKE DETERMINATION REGARDING TAKING ACTION BEYOND SOURCE CONTROL
CONTINUE WITH EVALUATION OF REMEDIAL OPTIONS AND SELECTION OF PREFERRED COURSE OF ACTION

Figure 1. A generalized flowchart which can be used to help make a sediment management decision regarding whether or not to take action beyond source control

How to Best Interpret the Data

Equally important to the collection of data is that sufficient attention be placed on thorough and comprehensive interpretation of the data. By employing scientifically sound methods of data interpretation, the information from an intensive sediment assessment can finally be integrated to make a decision to intervene (i.e., remediate contaminated sediment) or pursue source control and natural recovery as the preferred remedial option. A variety of data interpretation tools are available to make a decision (Table 2).

By employing scientifically sound methods of data interpretation, the information from an intensive sediment assessment can finally be integrated to make a decision to intervene or pursue source control and natural recovery as the preferred remedial option.

By way of example, a recently well-received approach could be used consistently across jurisdictions to determine the significance or severity of benthic community structure data or laboratory toxicity results (see Appendix 5). Reference conditions can be defined using an array of reference sites for comparison with test site data using multivariate methods. A reference site database is used to predict the structure of the benthic invertebrate community or the response of bioassay species for a test site. The test site's potential for a certain faunal community or bioassay endpoint can be based on variables that are least affected by anthropogenic impacts (e.g., geographic location, particle size distribution, major elements, etc.). The distribution of the reference sites provides the range of variation in unimpaired communities. The community at the test site can then be compared to this normal variability. The greater the departure from the reference sites, as measured in ordination space, the greater the certainty of environmental effects resulting from contaminants.

The consensus among community-based and agency RAP practitioners is that consistent application of sediment assessment and data interpretation methods across the regions is desirable (i.e., collect and interpret data similarly across Areas of Concern). Site specificity, however, remains important in applying tools due to local conditions, constraints, and nature of the chemical contamination.

To ensure that sediment management decisions consider restoration of beneficial uses in a comprehensive manner, one could also use a checklist in making a sediment management decision beyond source control. These key elements are presented and related to relevant data interpretation tools in Table 3.

Table 2. A matrix of data interpretation tools and references for making a sediment management decision beyond source control to restore beneficial uses as defined in the Great Lakes Water Quality Agreement

Use Impairment	Assessment Element	Data Interpretation Tools	Reference
Restrictions on fish and wildlife consumption	Bioaccumulation	Equilibrium partitioning, comparison to guidelines	Appendices 6, 7, 10, 12, and 14; Beltran and Richardson (1992)
Degradation of fish and wildlife populations	Community structure, bioaccumulation	Food web model, weight of evidence	Appendices 6, 12, and 14; Beltran and Richardson (1992)
Fish tumors or other deformities	Bioaccumulation, chemistry	Reference frequencies	Baumann (1992); Baumann *et al.* (1982)
Bird or animal deformities or reproduction problems	Bioaccumulation, community structure	Food web model, comparison to reference conditions, weight of evidence	Appendices 6, 12, and 14; Beltran and Richardson (1992)
Degradation of benthos	Community structure, toxicity (bioassays)	Comparison to reference conditions	Appendices 4, 5, 9, 10, 12, and 14
Restrictions on dredging activities	Chemistry, toxicity (bioassays) , stability*	Comparison to guidelines and/or reference conditions	Appendices 3, 8, and 10; U.S Army Corps of Engineers web site (www.wes.army.mil/el/dots)
Eutrophication or undesirable algae	Chemistry, stability	Modeling	Gore & Storrie, Ltd. (1991); Pennsylvania DEP's "The Lake Model" (1998)
Degradation of aesthetics	Chemistry, stability	Comparison to reference conditions	Heidtke and Tauriainen (1996)
Added costs to agriculture or industry	Chemistry, stability	Comparison to reference conditions	Park and Hushak (1998); Ontario MOE and Michigan DNR (1991)
Degraded phytoplankton and zooplankton populations	Bioaccumulation, chemistry, stability	Comparison to reference conditions, target nutrient loads	Bierman *et al.* (1983)
Loss of fish and wildlife habitat	Chemistry, bioaccumulation, toxicity, benthos, stability	Comparison to reference conditions, weight of evidence	Appendices 6 and 12; Minns *et al.* (1996)

*physical sediment characteristics, quiescent vs. energetic site characteristics, etc.

Table 3. A checklist of key elements to consider in making a sediment management decision beyond source control

ASSESSMENT ELEMENT	REFERENCE FOR FURTHER INFORMATION
Characterization of the nature and extent of chemical contamination	Appendix 3, 5, and 9; IJC (1987); IJC (1988)
Measurement of toxicity endpoints (lethal and sublethal chronic effects)	Appendix 4, 5, 9, 10, 13, and 14
Assessment of bioaccumulation/ biomagnification potential	Appendix 10, 12, and 14
Characterization of benthic communities	Appendix 5, 9, 10, and 12
Evaluation of the nature and extent of fish tumors and abnormalities	Appendix 12
Assessment of human health risk from sediment contamination	Appendix 7 and 14
Assessment of wildlife risk from sediment contamination	Appendix 6, 12, and 14
Assessment of fish and other aquatic life risk from sediment contamination	Appendix 14
Evaluation of the physical stability of contaminated sediment deposits (i.e., Would a storm scour the sediment from the river resulting in a pulsed loading of contaminants to the lake?)	Beltran and Richardson (1992); U.S. EPA (1993); Lick (1992); and Cardenas and Lick (1996)
Determination of control of contaminants at source (i.e., have upstream sources of contamination also been controlled/terminated?)	IJC (1987)

The data interpretation tools presented in Table 2 and the checklist in Table 3 have been developed to help make a decision regarding whether the scientific evidence warrants consideration of taking action beyond source control. It is beyond the intent of this report to address how decisions are tempered by factors other than the science-based tools discussed above. Once a decision has been made to intervene, however, those as well as the following additional elements require attention:

- engineering factors (e.g., technical feasibility, contaminant reduction, permanence of remedial options like capping, *in situ* treatment, dredging and disposal, etc.);
- economic factors (e.g., cost effectiveness, economic benefits);
- social factors (e.g., public acceptance, partners' opinions, adherence to public use goals, conflicting actions); and
- long-term monitoring considerations.

IV. CONCLUDING REMARKS AND RECOMMENDATIONS

More research is needed to quantify the relationships between contaminated sediment and known use impairments. The ability to predict ecological benefits is an important management need.

Despite the guidance provided herein, there are currently few, if any, simple or proven methods to predict recovery of use impairments based on sediment cleanup. More research is needed to quantify the relationships between contaminated sediment and known use impairments. The concept of ecological benefit forecasting (i.e., predicting ecological benefits and restoration of beneficial uses) is an important management need which if accomplished, would be a substantial step forward.

The Great Lakes WQB (1998a), in its "Review of Government Resources and Changing Program Thrusts as They Relate to Delivery of Programs Under the Great Lakes Water Quality Agreement" report, has recognized the importance of evaluating program effectiveness based on measuring ecosystem results. Further, the Great Lakes WQB (1998b) has recommended in its 1997 public meeting report "If You Don't Measure It, You Won't Manage It", that the IJC, Parties, Jurisdictions, and RAP/LaMP groups must place greater emphasis on reporting both process milestones (e.g., securing funding for implementation, volumes of contaminated sediment removed or mass of contaminants removed) and ecosystem milestones (ecosystem results as defined in the Great Lakes Water Quality Agreement) to help build a record of success. It is hoped that the data interpretation tools compiled in this report will help individuals and RAP teams make sediment management decisions regarding whether or not to take action beyond source control, and will also help ensure achievement of the long-term goals of restoring beneficial uses in Areas of Concern.

SedPAC's primary intent with this document is to share advances in data interpretation tools regarding sediment management decision-making with RAP practitioners. Presently, a great deal of data have been collected on the physical, chemical, and biological elements that modify contaminant bioavailability and ecological effects. The literature contained and cited herein can help guide RAP practitioners through a transparent use restoration decision-making process.

In addition to this review of data interpretation tools, SedPAC recognizes that the IJC can offer more assistance in the efforts to overcome obstacles to sediment management. Specifically, SedPAC recommends:

1.) **that the Commission recommends to the Parties and Jurisdictions that they develop and reach agreement on methods or programs to predict and measure successful ecological recovery in Areas of Concern (e.g., ecological benefit forecasting, monitoring and surveillance programs to measure use restoration); and**

2.) **that the Commission recommends to the Parties and Jurisdictions that they establish procedures for consistent data collection and interpretation across Areas of Concern, recognizing the importance of site specificity in applying methodologies and tools.**

In addition, the Commissioners have an important role to fulfill in overcoming obstacles to sediment management for beneficial use restoration. SedPAC recommends that Commissioners:

3.) **meet with industrial representatives in selected Areas of Concern to champion and catalyze sediment remediation;**

4.) **meet with stakeholders in the sediment session being convened at the Commission's Biennial Forum in Milwaukee to learn about current local obstacles and identify how the Commissioners can help overcome these obstacles and catalyze local initiatives; and**

5.) **develop and implement an IJC public outreach strategy to help make contaminated sediment management a priority throughout the basin.**

Further, SedPAC recommends:

6.) **that the Commission direct its WQB to define the conditions under which natural recovery is selected as the preferred remedial option in sediment management during the 1999-2001 priorities cycle.**

Deciding when to intervene is embedded with multiple elements. Data interpretation tools and techniques are a central element in developing the sediment management strategy. This report is one in a series that will explore a number of aspects affecting sediment management, including linking sediment cleanup to ecological recovery and restoration of beneficial uses, as well as economic benefits that may accrue from effective management of contaminated sediment.

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VI. APPENDICES

APPENDIX 1

WORKSHOP FORMAT AND AGENDA

Workshop format

Agency, academic, and industrial leaders in the field of sediment management met at the University of Windsor's Great Lakes Institute for Environmental Research for a two day workshop on December 1-2, 1998 to discuss and provide advice on the use of data interpretation tools used to make sediment management decisions regarding whether or not to take action beyond source control. Forty-four people participated (Appendix 2).

On the first day of the workshop, speakers presented eleven different case studies on data interpretation tools for making a decision beyond source control (Appendices 3-13). Case study presentations included the following:

- Sediment Assessment and Remediation: Ontario's Approach (Rein Jaagumagi - see Appendix 3);
- Thunder Bay Creosote Cleanup. A Case Study in the Application of Ontario's Approach to Sediment Assessment and Remediation (Rein Jaagumagi - see Appendix 4);
- Decision Making for Sediment: Numeric Biological Guidelines (Trefor Reynoldson - see Appendix 5);
- Ecological Risk Assessment Applied in the Saginaw River/Saginaw Bay (Lisa Williams - see Appendix 6);
- The Application of Human Health Risk Assessment Techniques at Sediment Contaminated Sites Under the Superfund Program (Marian Olsen - see Appendix 7);
- U.S. Army Corps of Engineers Dredged Material Evaluation and Assessment Procedures (Bob Engler - see Appendix 8);
- 1994/1995 St. Clair River Sediment Program Defining Spatial Extent and Environmental Conditions (Tim Moran and Scott Munro - see Appendix 9);
- Trenton Channel/Detroit River Sediment Assessment and Remediation (Russell Kreis - see Appendix 10);
- A Framework for Interpreting Narrative Sediment Quality Standards (Jim Keating - see Appendix 11);
- Ecological Risk Assessment for the Contaminated Harbor Sediment Adjacent to the Ashland Lakefront Property - Kreher Park (Bob Paulson - see Appendix 12); and
- The SED-TOX Index for the Assessment and Ranking of Sediment Hazard Potential: How is it Useful in Decision-Making? (Manon Bombardier - see Appendix 13).

In addition, three other case studies of data interpretation tools and approaches were submitted in writing, but not given in oral presentation because of time constraints. These included:

- Contaminated Sediment: When is Cleanup Required? The Washington State Approach (Teresa Michelsen - see Appednix 14);
- Application of Computer Modeling and Biomonitoring in Decision Making for the St. Clair River Area of Concern (John Alexander McCorquodale, Maciej Tomczak, and Gordon Douglas Haffner - see Appendix 15);
- Testing and Evaluation Procedures for Great Lakes Dredged Material Evaluations Developed by the U.S. Environmental Protection Agency and U.S. Corps of Engineers (Jan Miller - see Appendix 8).

On the second day of the workshop, attendees were divided into two breakout groups to focus on specific topics and questions regarding decision-making frameworks, key data elements to be examined in these frameworks, and various technical tools. Each group then presented a summary of its findings and advice (Appendices 16-17). A facilitated discussion to synthesize the output of both groups followed, including a discussion of how best to transfer this technology to RAP participants.

Workshop agenda

WORKSHOP TO EVALUATE DATA INTERPRETATION TOOLS USED TO MAKE SEDIMENT MANAGEMENT DECISIONS

Great Lakes Institute for Environmental Research, Room 250
2990 Riverside Drive W., Windsor, Ontario
December 1-2, 1998

CO-SPONSORED BY: U.S. EPA, Environment Canada, IJC's Great Lakes Water Quality Board, and University of Windsor's Great Lakes Institute for Environmental Research

GOAL: To exchange and examine the tools that are used as a means for arriving at a decision regarding whether or not to take action beyond source control. Participants leave with a new set of tools they can apply locally.

WHO WAS INVITED: This was an expert level workshop for agency, academic, and industrial leaders in the field. Consideration will be given at the workshop on how best to transfer the information to RAP practitioners.

Tuesday December 1, 1998

8:30 **Welcome, Workshop Objective**
Art Szabo - Director of the Great Lakes Institute for Environmental Research, Kelly Burch - Water Quality Board

8:40 **Opening Comments**
Dave Cowgill, Griff Sherbin - Sediment Priority Action Committee Co-Chairs

8:50 **Background, Problem Description**
Gail Krantzberg - Ministry of Environment

Presentations of data evaluation tools which are used in decision-making, and case studies to highlight their use:

9:00 **Canada/Ontario Approach Applied in Thunder Bay, Elmira, Cornwall, and Severn Sound**
Rein Jaagumagi - Ministry of Environment, Trefor Reynoldson - Environment Canada

9:50 **Ecological Risk Assessment Applied in the Saginaw River/Saginaw Bay**
Lisa Williams - U.S. Fish and Wildlife Service

10:25 Break

10:40 **Human Health Risk Assessment Applied at Superfund Sites**
Marian Olsen - U.S. EPA

11:15 **A Reference-Based Tiered Approach Used by the U.S. Army Corps of Engineers**
Bob Engler - U.S. Army Corps of Engineers

11:50 Lunch

12:50 **Lambton Industrial Society/Pollutech Enviroquatics Ltd. Approach Applied in the St. Clair River**
Scott Munro - Lambton Industrial Society, Tim Moran - Pollutech Enviroquatics Ltd.

1:25 **U.S. EPA Approach Applied in the Trenton Channel of the Detroit River**
Russ Kreis - U.S. EPA

2:00 **A Framework for Interpreting Narrative Sediment Quality Standards**
Jim Keating - U.S. EPA

2:35 **Break**

2:50 **Weight of Evidence Approach Applied at the Ashland Coal Gasification Site**
Bob Paulson - Wisconsin DNR

3:25 **Development of a Toxicity Testing Index Approach**
Manon Bombardier - Environment Canada

4:00-5:00 **Summary, Questions, and Comments**
Dave Cowgill, Griff Sherbin - Sediment Priority Action Committee Co-Chairs, John Hartig - Water Quality Board

Wednesday December 2, 1998

8:30-12:00 **Breakout session**
Breakout Facilitators: Marcia Damato - U.S. EPA, Gail Krantzberg - Ministry of Environment

Breakout Groups will discuss the following:

Decision-Making Framework Elements:

- Protocols and testing guidance
- Interpretation guidance for individual data types
- Rules for combining data types to arrive at an overall decision
- Modeling guidance including human health/ ecological risk models for bioaccumulation, sediment resuspension/ transport, and natural recovery

Alternative Frameworks:

- Tiered
- Weight of Evidence

Technical Tools:

- Sediment chemistry, bioassays, benthic community data, lab bioaccumulation, and tissue residue

12:00 Lunch

1:00 **Presentations from Breakout Groups**

2:00 **Synthesis and Recommendations**
Facilitated

3:30 **Discussion of Technology Transfer to RAP Participants**
Facilitated

4:00 **Closing Remarks**
Kelly Burch - Water Quality Board, Gail Krantzberg - Ministry of Environment

APPENDIX 2

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APPENDIX 3

SEDIMENT ASSESSMENT AND REMEDIATION: ONTARIO'S APPROACH

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Introduction

The Ontario Ministry of the Environment has developed a protocol for determining when sediment is contaminated to a level that requires remedial action. The protocol is based upon sediment guidelines, combined with a risk assessment approach.

The first step is comparison of sediment contaminant concentrations with sediment quality criteria. The Provincial Sediment Quality Guidelines (PSQGs) are a set of numerical guidelines, using a tiered approach, that were developed for the protection of sediment-dwelling (benthic) organisms. The Guidelines also protect against biomagnification of contaminants through the food chain from sediment contaminant sources.

Provincial Sediment Quality Guidelines (PSQGs)

The PSQGs define three levels of eco-toxic effects and are based on the chronic, long-term effects of contaminants on benthic organisms. The essence of the guidelines and their significance are summarized below. Details are provided in Persaud *et al.* (1993).

The No Effect Level. This is intended as the level at which contaminants in sediment do not present a threat to water quality and uses, benthic biota, wildlife, or human health. The No Effect Level (NEL) is principally designed to protect against biomagnification through the food chain. Partitioning approaches in conjunction with Provincial Water Quality Objectives (PWQOs) are used to set these guidelines, since with appropriate safety factors PWQOs/Gs are designed to protect against biomagnification.

A PSQG NEL is derived through the equation: $PSQG = K_{OC} \times PWQO/G$

where:

PSQG = sediment quality guideline normalized to the sediment organic carbon content (TOC) of 1%
K_{oc} = organic carbon partitioning coefficient
PWQO/G = Provincial Water Quality Objective/Guideline

The Lowest Effect Level. The Lowest Effect Level (LEL) is the level that can be tolerated by the majority of benthic organisms. It is derived using field-based data on the co-occurrence of sediment concentrations and benthic species. The procedure used is based on the Screening Level Concentration (SLC) method described in Neff *et al.* (1986).

The calculation of the SLC is a two step process and is calculated separately for each parameter. In the first step, the individual SLCs (Species SLCs) are calculated for each benthic species. The sediment concentrations at all locations at which that species was present are plotted in order of increasing concentration. From this plot, the 90th percentile of this concentration distribution is determined. The 90th percentile was chosen to provide a conservative estimate of the tolerance range for that species. This would serve to eliminate extremes in concentrations that may be due to specific and unusual sediment characteristics.

In the second step, the 90th percentiles for all of the species present are plotted, also in order of increasing concentration. From this plot, the 5th percentile is calculated and this level becomes the LEL guideline.

The Severe Effect Level. This level represents contaminant concentrations in sediment that could potentially eliminate most of the benthic organisms. The procedure used is identical to the calculation of the LEL except that the 95th percentile of the SLC (the level below which 95% of all SSLCs fall) is calculated in the second step of the SLC calculation, and this level becomes the Severe Effect Level (SEL) guideline.

Table 1: Provincial Sediment Quality Guidelines for metals and nutrients (values in mg/kg dry weight unless otherwise noted)

Parameter	No Effect Level	Lowest Effect Level	Severe Effect Level
Arsenic	-	6	33
Cadmium	-	0.6	10
Chromium	-	26	110
Copper	-	16	110
Iron (%)	-	2	4
Lead	-	31	250
Manganese	-	460	1100
Mercury	-	0.2	2
Nickel	-	16	75
Zinc	-	120	820
TOC (%)	-	1	10
TKN	-	550	4800
TP	-	600	2000

Metal concentrations determined using Aqua-Regia digestion
- = denotes insufficient data/no suitable method
TOC = Total Organic Carbon
TKN = Total Kjeldahl Nitrogen
TP = Total Phosphorus

Table 2: Provincial Sediment Quality Guidelines for organic compounds (values in mg/kg dry weight unless otherwise noted)

Compound	No Effect Level	Lowest Effect Level	Severe Effect Level*
Aldrin	-	0.002	8
BHC	-	0.003	12
-BHC	-	0.006	10
-BHC	-	0.005	21
-BHC	0.0002	(0.003)	(1)
Chlordane	0.005	0.007	6
DDT(total)	-	0.007	12
op+pp-DDT	-	0.008	71
pp-DDD	-	0.008	6
pp-DDE	-	0.005	19
Dieldrin	0.0006	0.002	91
Endrin	0.0005	0.003	130
HCB	0.01	0.02	24
Heptachlor epoxide	-	0.005	5
Mirex	-	0.007	130
PCB(total)	0.01	0.07	530
Anthracene	-	0.220	370
Benz[a]anthracene	-	0.320	1,480
Benzo[k]fluoranthene	-	0.240	1,340
Benzo[a]pyrene	-	0.370	1,440
Benzo[g,h,i]perylene	-	0.170	320
Chrysene	-	0.340	460
Dibenzo[a,h]anthracene	-	0.060	130
Fluoranthene	-	0.750	1,020
Fluorene	-	0.190	160
Indeno[1,2,3-cd]pyrene	-	0.200	320
Phenanthrene	-	0.560	950
Pyrene	-	0.490	850
PAH (total)**	-	4	10,000

- = Insufficient data to calculate guideline

* = Numbers in this column are expressed as mg/kg organic carbon and are converted to bulk sediment values by multiplying by the actual TOC concentration of the sediment (to a maximum of 10%). For a sediment sample with a PCB value of 30 mg/kg and a TOC of 5%, the PCB SEL is converted to a bulk sediment value for a sediment with 5% TOC by multiplying 530 x 0.05 = 26.5 mg/kg and gives the SEL guideline for that sediment. The measured value of 30 mg/kg is then compared with the bulk sediment value, and is found to exceed the guideline.

** = PAH (total) is the sum of 16 PAH compounds: Acenaphthene, Acenaphthylene, Anthracene, Benzo[k]fluoranthene, Benzo[b]fluorene, Benzo[a]anthracene, Benzo[a]pyrene, Benzo[g,h,i]perylene, Chrysene, Dibenzo[a,h]anthracene, Fluoranthene, Fluorene, Indeno[1,2,3-cd]pyrene, Naphthalene, Phenanthrene and Pyrene.

Application of the PSQGs

The PSQGs shown in Tables 1 and 2 are used in making decisions in relation to a number of sediment-related issues ranging from dredged material disposal to determination of remedial action for contaminated sediment.

In an area as geologically diverse as Ontario, local natural sediment levels of the metals may vary considerably and in certain areas, such as wetlands, the organic matter content and nutrient levels may be naturally high.

Metals. In areas where local background levels are above the LEL, the local background level will form the practical lower limit for management decisions. In some waterbodies, surficial sediment upstream of all discharges may be acceptable for calculation of background values. Where it cannot be shown that such areas are unaffected by local discharges, the pre-colonial sediment horizon is used. Site-specific background for metals is calculated as the mean of 5 replicate samples from surficial sediment that has not been directly affected by man's activities or from the pre-colonial sediment horizon. Alternatively, the mean background values for the Great Lakes Basin as calculated in the guidelines may be used.

Nutrients. Areas of high natural organic matter content, such as marshes and other types of wetlands, can be readily distinguished from those resulting from anthropogenic sources. In such cases, for the nutrients listed in Table 1, the local background would serve as the practical lower limit for management action.

It is also recognized that long-range sources such as atmospheric deposition have contributed to accumulation of organic compounds in areas remote from any specific source. Therefore, in those areas where specific sources cannot be determined, the practical lower limit for management action is the Upper Great Lakes deep basin surficial sediment concentration.

If the sediment concentration exceeds the local background value, the next step is to determine whether the sediment poses a threat to aquatic life. The severity of this effect is determined using a number of biological assessment techniques.

If the concentration of the contaminant in the sediment exceeds the SEL then the MOE Sediment Bioassay tests for acute toxicity, described in Bedard *et al.* (1992), are required.

Assessment of contaminated sediment

Initial sediment assessment. The most important preliminary piece of information necessary for sediment evaluation is chemical data, which are compared against the PSQGs as well as background levels. The

importance of sediment assessment is that it provides a good indication as to whether any further effort is required in studying sediment contamination in a given area. From a sediment management standpoint, the LEL is the point at which low-level concerns arise in relation to future worsening of the situation if existing sources are not controlled. This level would rarely warrant concerns from a remediation standpoint unless dealing with a spill in areas where the background sediment is below the LEL.

The SEL is the level that raises major concern from an environmental management standpoint. The urgency of a management response can be established by obtaining additional information through laboratory sediment bioassays on the toxicity of the sediment.

Based on comparison with the PSQGs and background levels, there are three possible outcomes from a sediment evaluation:

- The sediment is clean (i.e., all parameters tested are below the LEL) and no further action is required unless the situation changes as a result of new discharges or material spills.
- The concentrations of contaminants in sediment are above the LEL and further testing is warranted. This will necessitate gathering additional information of a quality and quantity that would facilitate a thorough review of the site and may include both chemical and biological tests.
- The sediment has been shown to have contaminant levels at or above the SEL and biological assessment is required. The detailed studies must include laboratory biological testing for potential toxic effects as described in the PSQG document. Determination of biological cleanup targets may also be necessary.

Degree of chemical contamination. After the initial assessment, the extent and degree of sediment contamination is assessed through mapping, which will permit delineation of "hot spots" and areas of lesser degrees of contamination. It is especially important to determine the outer boundaries of the affected area, as well as the depth of sediment contamination, since this will define the area of any future remediation and permit calculation of volumes of material to be dealt with.

A second but equally important aspect of sediment characterization is determination of the physical characteristics of the area. In many cases, areas of contaminated sediment may act as sources of contaminated material to adjacent or downstream areas through resuspension of material. The potential for resuspension of contaminated material through erosion (i.e., through fluctuations in discharge, currents, wave patterns, and physical obstructions such as lakefill structures, dams, and weirs) needs to be carefully assessed. Characteristics such as seasonal and yearly net sediment erosion or deposition, which may affect subsurface contamination, should be determined since this will have a major impact on the determination of a remediation plan.

The biological significance of the chemicals. An assessment of the severity of biological effects of contaminants in sediment is normally required as part of the protocol for sediment that exceeds the LEL or the SEL. Biological assessment is also necessary, since the decision to remediate is usually based on biological effects.

The nature of the effects can be broken down into two main categories: effects on individuals and effects on communities. This is achieved through a number of components such as:

- Benthic community structure and functional analysis
- Fish community studies
- Sediment bioassays (including testing with water column organisms)
- Uptake studies (e.g., caged fish and caged mussel studies)
- Tissue resides in *in-situ* organisms (e.g., sport fish, young-of-the-year fish, *in situ* benthic organisms)

A number of evaluation techniques are available to carry out a comprehensive biological assessment. These include:

- Benthic and fish community structure - functional group analysis. These studies consider the effects of contaminants at the population or community level. While generally unable to pinpoint a cause-effect relationship, they can provide a useful measure of overall ecosystem health.

- Sediment bioassays. These use benthic organisms such as chironomids, mayflies, oligochaetes, and fathead minnows to assess chronic and acute toxicity of sediment. These studies can be designed to examine mortality, reproductive impairment, mutagenicity, and a range of sub-lethal effects on individuals. They are most effective, however, in determining the potential toxicity of contaminated sediment (usually as a measured effect over a certain exposure period). The specific causative agent is difficult to isolate, especially when dealing with mixtures of contaminants. The sediment used in these tests is usually disturbed, which in most cases heightens the biological availability of the contaminants in the sediment and also through release to the water column. As a result, this test can be considered as representing the worst case scenario.

- Uptake studies. These use caged mussels, leeches, and/or caged fish placed on, or suspended just above, the sediment to determine the levels of contaminants in the water column at the study site. Similarly, this approach can be applied in the laboratory through the exposure of cultured juvenile fathead minnows to test and control sediment. Both field and laboratory studies can provide a good indication of the release of contaminants to the water column from sediment. This information, therefore, is an indirect measure of the impacts of contaminants in sediment on water use impairments.

- Contaminant residues in *in situ* organisms. Analysis of benthic organisms and fish tissue for contaminant residues can be used to determine availability of contaminants from sediment. In most cases, sediment ingesting organisms are chosen, whether benthic organisms or bottom-feeding fish, since these are most likely to accumulate contaminants directly from the sediment. This provides a measure of the availability of contaminants to biota, and the potential for transfer of contaminants through the food chain. Coupled with the mussel studies, it can provide an indication of the relative importance of the water and sediment pathways for bioaccumulation. Analysis of sport fish and comparison with consumption guidelines provides a measure of direct danger to humans through consumption of contaminated fish. Levels are designed to protect human consumers, but also provide an indication of the availability of contaminants from sediment and other sources such as prey.

A number of different biological tests are necessary at any one site in order to provide a good indication as to whether the study area presents a danger to organisms, including humans, since no single indicator can provide all the necessary information for management decision-making. This type of information will also assist in determining where to concentrate any remedial actions.

The source or origin of contaminants. Concurrent with environmental data gathering, efforts should be made to obtain information on contaminant input to the area. The usual sources of contaminants can be grouped into municipal (which will likely contain the widest range of chemicals), industrial, urban runoff, agricultural, mining, and atmospheric fallout. Knowledge of the sources will provide a good framework of the type of chemical analysis required and will also aid decision-making on remediation. In some instances it may be necessary to test material emanating from such sources to determine their current toxic impact.

Establishing the need for remediation. Once the information has been gathered and the data evaluated, the need for remediation should be assessed. This is based on evaluating the considerations listed below:

Sources:

- Presence of active contaminant sources to the area

- Types of contaminant sources - point sources or non-point (diffuse) sources

Contaminant concentrations:

- Sediment contaminants exceed LEL for 1 or more contaminants

- Sediment contaminants exceed SEL for 1 or more contaminants

Contaminant characteristics:

- Types of contaminants - i.e., nutrients, metals, persistent organics
- Presence of contaminants as a mix of metals and organics

Biological effects:

- Characteristics of benthic community - benthic organisms are abundant and evenly distributed, or the benthic invertebrate community is species poor and consists mainly of pollution tolerant organisms
- *In situ* and laboratory biological tests and sport fish data show uptake of contaminants
- Sediment results in chronic effects on aquatic organisms, or is acutely toxic

Physical factors:

- Sediment type - i.e., presence of fine-grained material (sand/clay/mud)
- Physical characteristics of area - i.e., depositional or erosional
- Presence of factors that may alter the physical nature (e.g., lakefills, flow changes, etc.) of the site

In instances where some or all of the biological effects studies yield negative results, then the reasons for such findings must be fully explored. In cases where significant adverse effects have been noted in sediment bioassays, effort should be directed towards determining whether this is in fact due to chemical factors, rather than physical factors, such as unsuitable sediment type. For example, a combination of contaminated sediment and unsuitable sediment type could result in stresses on the test organisms which, individually, would not have elicited such a severe response.

The types of adverse effects are evaluated on a case-by-case basis. The only clear-cut case is where sediment is acutely toxic. Where chronic effects and/or bioaccumulation are the primary biological effects, the need for remediation must include other considerations. These are often based upon identified use impairments and use restorations.

Setting a goal

The setting of cleanup goals can be guided by use impairments to be restored. The International Joint Commission (1985) in its "listing/delisting" criteria for Great Lakes Areas of Concern has identified several use impairments. These include:

- Restrictions on fish and wildlife consumption
- Tainting of fish and wildlife flavor
- Degraded fish and wildlife populations
- Fish tumors or other deformities
- Bird or animal deformities or reproductive problems
- Degradation of benthos
- Restrictions on dredging activities
- Restrictions on drinking water consumption or taste and odor problems
- Added costs to agriculture or industry

Sediment alone may not contribute directly to this extensive list of use impairments, but through the slow release of contaminants in some areas, may be a source of chemicals to the water column. To progress from a

contaminated sediment problem to the restoration of designated uses in an area will require a strategy that involves a phased approach, likely over several years, to achieve significant improvements. It is imperative that any cleanup aimed at use restoration be based on a realistic schedule that allows sufficient time for source controls to take effect and the practical constraints of removing or covering over contaminated sediment.

Factors to consider in setting cleanup goals include:

- The size of the area affected needs to be clearly defined since it will have a significant bearing on the remedial option chosen from both a cost and technology perspective.
- The uses the area is put to and the potential for this area to affect adjoining areas through the spread of contaminated sediment must be considered. Uses may include protection of fisheries and benthic organisms. There is a need to consider both the toxic and bioaccumulative potential of contaminants. In previous sections, the need to look at a range of tests was indicated. This becomes critical at this stage since the severity of the effect will play a major role in arriving at the final decision.
- From a human health perspective, compounds that are persistent and pose a threat to water supplies or fish and wildlife will be weighted differently from compounds that do not pose similar threats. In some cases recreational/aesthetic considerations may be the driving force in a cleanup study.
- The potential for recontamination must be examined from the point of view of existing and proposed land use and source controls. Existing and new industries must incorporate features that will not lead to sediment contamination.
- There is a need to consider whether sediment removal will create additional problems, such as the exposure of historical contamination in deeper layers of the sediment. Care must be taken to ensure that the full depth of the problem has been adequately defined.
- The physical environment of the area needs to be considered. The potential for resuspension of contaminated sediment, with resultant contamination of adjacent or downstream areas, will be an important factor in developing a remediation plan.

With the exception of spills, which must be cleaned up immediately, the most urgent need in environmental management is to protect the ecosystem from further abuse. Thus, source control must be the foundation of remedial action.

Conclusion

Consideration of remedial action in an area of contaminated sediment requires the development of a cleanup goal. This goal should be based on the "desired state of the environment" or developed in support of certain "attainable" uses. Where feasible, chemical guidelines provide a very convenient tool for setting cleanup goals, though these must be used with care, since most chemical guidelines have been developed for broad use and may require some adjustment when applied to specific sites. The final goal could also include intermediate goals, since the achievement of the goal can be phased over time or over a sequence of activities.

The ideal cleanup goal for restoration of contaminated sediment will always be the level that provides for the protection of all sediment uses. To this end, the cleanup target should be derived with heavy reliance on biological tests, rather than guideline levels. In many cases, the practical limits to cleanup will be dictated by the local background or ambient values, since cleanup to levels lower than these will be impractical and counterproductive. However, even cleaning up to this level will not always be feasible, especially when the area under consideration is large or where there are ongoing sources of contamination. Such areas may require a multi-phased approach, spread out over time, to achieve source control before any remediation work is undertaken.

In addition to these technical considerations, the final decision as to the proper course of action must also be based on considerations of social and economic criteria.

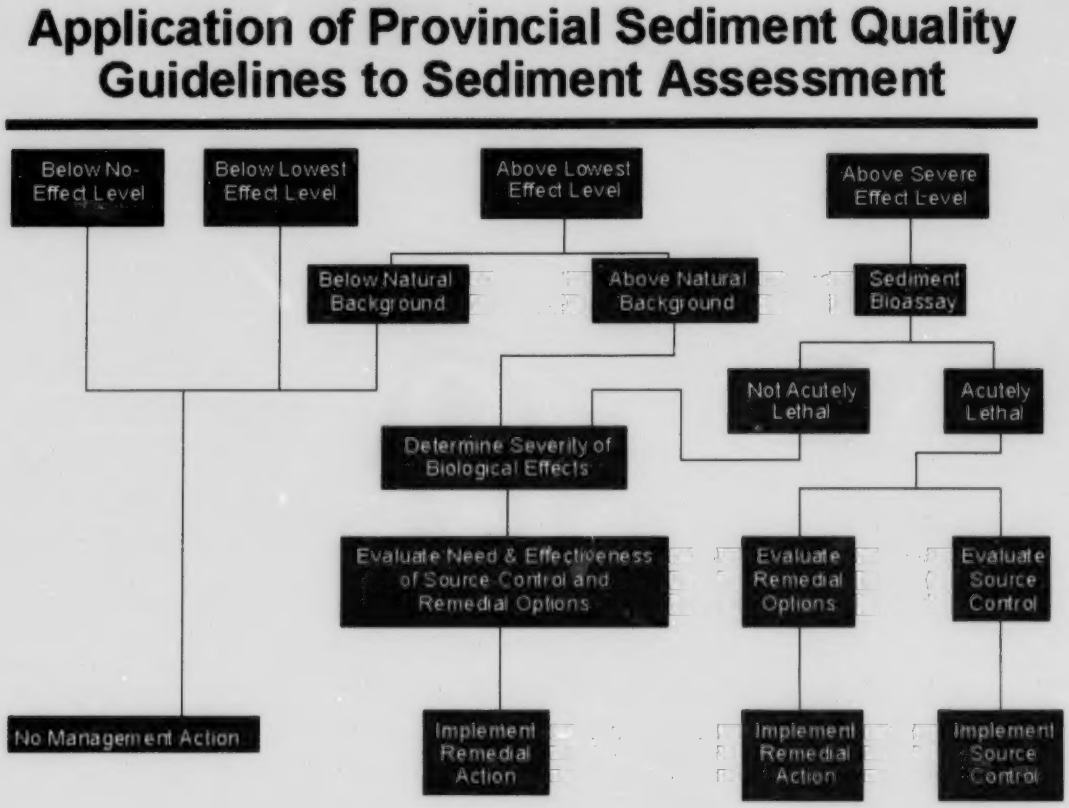

Figure 1.

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APPENDIX 4

THUNDER BAY CREOSOTE CLEANUP: A CASE STUDY IN THE APPLICATION OF ONTARIO'S APPROACH TO SEDIMENT ASSESSMENT AND REMEDIATION

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Introduction

The Northern Wood Preservers Inc. site in Thunder Bay Harbour has, under various owners, produced creosoted wood products such as railway ties and telephone poles, as well as treated lumber using pentachlorophenol, for over 50 years. Earlier studies have indicated that creosote residues have accumulated in sediment adjacent to the site, often to levels in excess of the Severe Effect Levels (SEL) of the Provincial Sediment Quality Guidelines (PSQGs) (Beak Consultants, Ltd. 1988; Hayton 1989). In addition, dioxins and furans (primarily heptachloro- and octachloro- dioxins and furans) have been identified in sediment adjacent to the site (Beak Consultants, Ltd. 1988). The plant is on a dock 200 m wide that extends approximately 300 m into the harbour. Seepage from the site is believed to be the source of the contaminants.

The Ontario Ministry of the Environment and Environment Canada undertook a joint investigation in 1995 to determine the extent and degree of sediment contamination using biological tests. This information would be used to determine which area needed to be remediated in accordance with the protocol developed by the Ministry (Jaagumagi and Persaud 1996). The protocol required biological effects testing using multiple endpoints when contaminant levels exceed PSQGs (Persaud *et al.* 1993).

Methods

In order to determine the extent of contamination for cleanup evaluation, dense sampling of the area based on a grid system was undertaken. Preliminary investigation showed that most of the creosote residues were within 100 m of the site. In order to better delineate the gradation within the 100 m zone and develop a detailed sediment contaminant map of the area, sediment samples were collected at 25 m intervals along a total of 14 transect lines radiating out from the dock. Beyond the 100 m zone, samples were collected 50 m apart to a maximum distance of 500 m. A total of 93 stations were sampled for sediment PAH and TOC.

Surficial sediment samples (top 5 cm) were collected with a standard 9" x 9" (23 x 23 cm) stainless steel Ponar grab sampler. Three replicate samples were taken at each location and the top 5 cm from each replicate were combined and mixed to form a single sample. The samples were homogenized from which sub-samples of sediment were collected into appropriate sample containers for analysis. Samples for PAH (scan of 16 individual compounds) and TOC analysis were collected at 71 sites, while additional analysis for metals, PCBs, organochlorine pesticides, chlorophenols, and chlorobenzenes were undertaken at 30 of the sites, as well as at the two control sites. Sampling for dioxins and furans was only undertaken at selected sites along two transect lines and the control site. Standard Ministry analytical procedures were followed for all chemical analysis. These are described in detail in OMEE (1983).

Biological sampling involved a field and laboratory component: benthic community structure and sediment bioassays. Benthic samples were collected with a Ponar sampler along 4 transect lines as well as the two control sites. Samples were washed in the field to remove the fine debris using a U.S. # 30 mesh sieve. Three replicates were collected at each sampling station and the individual replicates were preserved separately in 10% formalin solution. Samples were subsequently sorted in the laboratory using a dissecting microscope, to separate the organisms from the debris. All three replicates were sorted individually, and from these results a mean value for each major taxonomic group was obtained. Subsequently, of the three replicates, the sample closest to the mean was selected for detailed identification of the organisms present. This involved identification to the generic level, with species identification where possible.

Sediment (top 15-20 cm) for laboratory sediment bioassays was collected with a Ponar sampler along the longest transect line (T-5.5; 13 test stations), transect T-EF (3 test stations), and one control station. Approximately 10 L of composited sediment were collected at each site, placed in polyethylene lined containers, and shipped in refrigerated transport to the Ministry laboratory. Details of the standard test procedure are provided in Bedard *et al.* (1992).

Results

Visual observations noted that the presence of creosote in sediment decreases with distance from the dock along all transect lines. In the area close to the dock (up to 100 m), creosote was often encountered on the sediment surface, especially along the north facing transects. Along one transect, significant quantities of creosote were encountered within 50 m of the dock. In some of these locations (within 25 m), liquid creosote formed over 50% of the sediment sample. Sediment creosote content decreased with distance from the dock. Beyond 100 m, creosote was encountered only as small blobs or drops in the subsurface layers of the sediment. Sediment type along all transect lines was similar, and consisted of a thin layer of fine silt overlying a silt/clay mix.

Chemical analysis. The distribution of PAH compounds in sediment showed that along the north and east sides of the site, sediment is characterized by high concentrations of PAH (up to 16,327 mg/kg), but these decrease rapidly with distance from the dock. Sediment concentrations were typically lower along the southern section of the east side and very low along the south side.

Along the north side, all transects yielded sediment concentrations of total PAH above 300 mg/kg within 25 m of the dock. However, by 50 m levels at most sites were below 200 mg/kg, and by 100 m concentrations were generally below 100 mg/kg total PAH. The exception was one transect where levels were above 300 mg/kg at 75 m from the dock. By 175 m, most sediment concentrations were below 20 mg/kg total PAH, and continued to decline to near background levels with increasing distance.

Transects to the east generally showed lower concentrations in sediment, with the exception of T-EF. This sediment contained substantial amounts of creosote, which is reflected in the higher sediment total PAH concentrations at these sites (up to 1,697 mg/kg). However, by 75 m, concentrations were below 80 mg/kg, and by 100 m were near 30 mg/kg.

Dioxin and furan analysis was undertaken on a limited number of transects. The predominant dioxin compounds in sediment were the hepta- and octa- chlorodibenzo-p-dioxins and the hepta- and octa-chlorodibenzofurans. The lower chlorinated forms were present at very low concentrations or were not detected. Typically, dioxin concentrations in sediment were higher than furan concentrations, with the octa-dioxin the predominant compound.

The distribution pattern of dioxins and furans around the site was similar to the PAH patterns. Concentrations were highest within 25 m of the dock (up to 360,000 pg/g OCDD) and decreased rapidly with distance from the dock. At 100 m, concentrations were less than 60,000 pg/g OCDD along the north and east transects.

Total TEQs for the dioxins and furans were also highest close to the dock and decreased rapidly with distance from the dock. Total TEQs were highest at sites within 25 m (up to 1,320 pg/g 2,3,7,8-T4CDD toxic equivalents), and suggests there is significant toxic and bioaccumulation potential associated with this sediment. However, since I-TEQs are based on mammalian toxicity, they may not be directly applicable to sediment.

In addition, the availability of highly chlorinated compounds, such as OCDD, are usually overestimated on the basis of partitioning coefficients, since molecular size has been suggested as limiting the passage of large molecules across cell membranes (Smith *et al.* 1988).

Benthic community structure. Benthic communities at the sample sites consisted primarily of oligochaetes and chironomids. Oligochaete density and diversity did not show any relationship with sediment PAH or PCDD/F levels (benthic samples were not collected in the creosote pool). Chironomid density was found to vary with sediment PAH concentrations, though the correlation was weak ($r = -.6794$; $p<0.05$). At distances greater than 150 m from the dock, neither showed a response to sediment PAH concentrations, which in this area were typically less than 30 mg/kg.

Laboratory sediment bioassay. Whole-sediment toxicity tests were conducted using the mayfly nymph, *Hexagenia limbata* (21-day exposure, survival and growth); the midge larva, *Chironomus tentans* (10-day exposure, survival and growth); and the juvenile fathead minnow, *Pimephales promelas* (21-day exposure, survival and chemical bioaccumulation). The battery of sediment toxicity tests used provide a number of endpoints, using organisms representing different trophic levels in order to measure differences in sediment quality. Spatial differences can be ascertained among test sites, as well as against low level contamination using appropriate control sediment.

Conductivity, pH, total ammonia, un-ionized ammonia and dissolved oxygen parameters were measured in the overlying water periodically during the course of the bioassay. pH ranged from 7.0 to 8.2 and conductivity from 279 to 447 umho/cm. Total ammonia readings in the overlying water were elevated for the majority of the test sediment and the reference sediment in the minnow sediment bioassay. Temperature averaged 20°C to 21°C for each bioassay.

Mayfly lethality results showed that within 100 m of the dock mortality was significantly higher at certain test sites relative to both negative and reference control sediment ($p<0.0073$). Sediment collected from Station T-5.5-75 m and T-EF-25 m was found to be acutely toxic (100% mortality). Observations made within the first 24 hours on these test chambers indicated that all of the animals were on the sediment surface. The mayflies showed minimal activity such as swimming or attempts at burrowing, thereby exhibiting strong avoidance behavior. Mayfly avoidance was also noted at Station T-5.5-25 m during the first four days and significant lethality (50% mortality) occurred by Day 21. Mayfly percent mortality was less than 10% for all control and test sediment beyond 100 m from the dock, with no statistical differences reported between the test sediment relative to either control sediment (Dunnett's *t*-test, $p<0.05$). Significant differences in the sub-lethal growth endpoint were measured among sites within a 100 to 150 m distance along T-5.5 ($p<0.0001$). The data, represented by individual fresh weights, showed a 50% growth reduction. Animals exposed to sediment collected from beyond 175 m attained similar or higher weights as the reference control mayflies.

Chironomid lethality and growth results indicate that within 100 m of the dock, significantly higher lethality was noted for three of the test sediment ($p<0.0001$). After 10 days, percent mortality ranged from 54% to 100%. Percent mortality for the midge ranged from 0% to 17% for sites beyond the 100 m distance. Control mortality ranged from 15% to 16% and was below the acceptable control mortality criterion of 25%. Sediment which yielded poor organism survival also resulted in lower body weights ($p<0.0001$). Similar to the mayfly assay, a 50% growth reduction in the midge was reported at Stations T-5.5-100 m, -125 m and -150 m and was significantly lower than those attained for control sediment along with the remaining test sediment ($p<0.0001$).

Fathead minnow lethality results showed that within the 100 m zone percent mortality among treatments were significantly different ($p<0.0001$). The most toxic sediment was Station T-5.5-75 m (73% mortality) and Station T-EF-25 m (93% mortality). Fish exposed to Station T-5.5-75 m and T-EF-25 m sediment exhibited a loss of equilibrium with a tendency to swim in a vertical manner within 24 hours after their introduction into the test chambers. Avoidance of the sediment, reduced swimming activity, and lack of sediment disturbance continued for at least four days. Mortality first occurred on Day 16 and continued until Day 21. Beyond the 100 m zone, percent mortality for Station T-5.5-150 m (66% mortality) and T-5.5-175 m (56% mortality) was significantly higher than both control minnow survival values. Minnow mortalities began on Day 14 and continued until Day 21. Sediment avoidance behavior was also noted within the first 48 hours for Station T-5.5-100 m and T-5.5-125 m exposures.

There is an association between the concentrations of PAH compounds measured in the bioassay test sediment and the degree of biological effects. The incidence of significantly higher organism mortality was

greater for sediment collected within 100 m of the dock. Acute toxicity to the mayfly and midge was measured along the two transects at distances of 25 m and 75 m, respectively. This sediment had an oily sheen and emanated a strong to moderate odor of a creosote-type compound.

Sediment collected between 100 m and 150 m along transect T-5.5 elicited significantly poorer midge and mayfly growth, relative to the sediment collected at a greater distance. Differences appear to be attributable to sediment total PAH concentrations. The LC_{50} for the mayfly and midge toxicity tests correspond to a sediment total PAH concentration of 150 mg/kg (based on field surficial sediment data). This value is similar to that reported for the amphipod, *Diporeia sp.*, in a dose-response laboratory experiment using PAH-spiked sediment in a 26 day test. Landrum *et al.* (1991) found a lethal exposure concentration of 100 mg/kg dry weight for total PAHs and the mode of toxic response was attributed to nonpolar chemical narcosis. The lack of minnow toxicity at Stations T-5.5-100 m and T-5.5-125 m appear to be correlated with fish avoidance to the contaminated sediment. Sediment collected at Station T-5.5-150 m and Station T-5.5-175 m resulted in significantly higher fish mortality relative to the negative and reference control sediment.

Chemical bioaccumulation concentrations in *Pimephales promelas* are based on unequal sample sizes due to the loss of animals and insufficient biomass across all treatments. A gradient in PAH accumulation was evident. Minnow tissue PAH concentrations were significantly correlated to the total PAH sediment concentrations ($r=0.76$; $p<0.01$). The highest total PAH concentrations in minnow tissues was recorded for station T-5.5-150 m (8,844 ng/g), followed by station T-5.5-125 m (3,953 ng/g). Trace amounts were also detected in minnows exposed to station T-5.5-100 m sediment. Non-detectable amounts were reported for the remaining control and test animals sediment (2,680 ng/g) and were representative of pre-exposure conditions.

The significantly lower chemical accumulation by minnows at station T-5.5-100 m, despite the relatively high sediment total PAH concentration of 213 mg/kg, could be due to the stronger avoidance behavior by the minnows. Reduced feeding and sediment disturbance could have resulted in lower chemical uptake. A similar effect, but to a lesser degree, occurred at station T-5.5-125 m. The relatively low accumulation of PAHs in fathead minnows is a result of the ability of many vertebrates, including fish, to metabolize PAHs and their rapid elimination through the bile, feces and urine (Kennedy and Law 1990). The enzyme system that is principally involved in the biotransformation of PAHs is the cytochrome P-450 mixed function oxidase (MFO) system. All these factors would maintain concentrations in the fish at levels lower than those found in the sediment. However, tissue concentrations remain a valuable measure of PAH relative availability.

Discussion

The Ministry protocol requires that where sediment contaminant concentrations exceed the PSQGs SEL guidelines, additional biological assessment needs to be undertaken. Levels of total PAH in sediment exceeded the SEL for total PAH at a number of sites adjacent to the dock (SELs are based on TOC correction and are site-specific).

The biological tests included both benthic community assessment and laboratory sediment bioassays. The biological testing is designed to determine the severity of the contamination. Benthic community studies determine the in-place effects of the contaminants on the existing organisms. Laboratory bioassays assess the effects of contaminants under controlled static conditions of heightened potential availability through both toxic effects (i.e., lethal and sub-lethal effects, such as growth inhibition) and chemical bioaccumulation.

Benthic community structure. The benthic communities within the 100m zone showed effects that could be attributed to sediment PAH concentrations. In particular, the chironomid community showed reductions in density with higher sediment concentrations of total PAH. Along transects T-5.5 and T-7/9, stations close to the dock (25 m) had significantly fewer chironomids and fewer taxa. Since substrate type and depth was relatively uniform along these two transects, the most likely factor was the increase in sediment total PAH concentrations (chironomid density did show a weak negative correlation with sediment total PAH). A simple regression of density versus sediment total PAH suggests that a 50% reduction in chironomid density would correspond to approximately 150 mg/kg total PAH in sediment.

Benthic community structure analysis indicated that beyond the 100 m zone, the benthic community as a whole did not show any direct effects of high sediment concentrations of PAH. Since much of the PAH is

present as discrete blobs or drops of oil, it would be relatively easy for most organisms to avoid these areas. This could account for the lack of response to higher PAH concentrations by many organisms. As noted, the distribution of the chironomid fauna does show a correlation with sediment contaminant levels along the north transect T-5.5, and the north-east transect T-7/9 as far as 150 m from the dock, and suggests that sediment PAH is affecting these organisms. Decreases in sediment total PAH concentrations are matched by increases in density of chironomids. The effects on chironomids suggest that below 30 mg/kg total PAH, there is no noticeable reduction in density.

Laboratory sediment bioassay. Sediment bioassay results indicate that there is an increase in both mortality and growth impairment in the benthic species in the sediment close to the dock. Within the 100 m zone, the sediment bioassay results indicate that sediment within 75 m of the dock along transect T-5.5 and within 25 m of the dock along transect T-EF was acutely toxic to both mayflies and chironomids. Sediment from the 100 m to 150 m distance along transect T-5.5 resulted in mayfly and midge growth impairment. At a distance of 175 m and beyond, both growth and mortality were similar to the control values and there was no detectable difference in effects between the test and control exposures. Sediment concentrations were at or below 30 mg/kg total PAH at these distances.

Therefore, at 30 mg/kg total PAH, there appeared to be no effect on these organisms relative to the control stations. Sediment bioassays tend to augment any impacts of sediment-bound contaminants. The process of preparing the sediment prior to testing results in a more complete mixing of any contaminants throughout the sediment, and also potentially heightens the bioavailability of the compounds through disturbance of the sediment. This test, in effect, simulated expected responses under dynamic conditions where mixing, resuspension, and deposition would occur. As a result, it appears from these test results that sediment up to and including 30 mg/kg total PAH could be left in place with no negative effects on benthic communities.

When the test results for the chironomid and mayfly toxicity tests were plotted against surficial field sediment total PAH concentrations, both the mayfly and the chironomid mortality data indicate that there was an increase in mortality with increasing sediment total PAH concentrations. Greater than 50% mortality was found to occur in sediment from the 25 m to the 75 m distance. This corresponded to the zone where sediment total PAH concentrations were in excess of 150 mg/kg. Regression analysis between surficial field sediment total PAH concentrations and bioassay test results found that the area of 50% mortality of chironomids coincided with the 150 mg/kg concentration of total PAH (lower 95% confidence limit) while the area of 50% mortality of mayflies coincided with approximately 130 mg/kg total PAH (lower 95% confidence limit).

Sediment beyond 75 m showed little toxicity to mayflies and chironomids, but there was growth inhibition associated with the sediment. Only at the 175 m distance, where concentrations in sediment were near 30 mg/kg total PAH, did growth rates increase. Growth rates for both mayflies and chironomids stayed high from 175 m to 500 m and equaled or exceeded levels of the control.

Minnow results indicate that there was an increase in mortality at some stations within 100 m of the dock. Along both transects T-5.5 and T-EF, mortality was highest at those locations where sediment total PAH concentrations were highest (i.e., 25 m along T-EF and 75 m along T-5.5).

The bioaccumulation data showed a gradient of PAH accumulation by fathead minnows such that locations close to the dock resulted in higher tissue residues. By 175 m north from the dock, there were no detectable levels in minnow tissues. Analysis of the data showed a significant correlation between tissue residues and sediment total PAH.

Cleanup strategy. The different levels of biological effects were used to define three zones of contamination. Each would merit a different cleanup strategy.

The first, representing the most contaminated conditions, was the area of heavy, visible contamination of sediment by creosote (a creosote 'pool'). This area was located along transect line T-5 and was found to include the 50 m distance, but did not extend to the 75 m distance. Since transects on either side (T-4.5 and T-5.5) of T-5 did not yield similar quantities of creosote in the sediment samples, this area appears to be confined to less than 50 m on either side. Cleanup of this area should proceed based on visual observation of creosote on the sediment surface. This area represents a continual source of creosote (and PAH contamination) to both the water column and adjacent sediment.

The second zone was defined on the basis of acute biological effects, i.e., greater than and including 50% mortality in the test organisms, and coincides with the area of high PAH (>150 mg/kg) and dioxin/furan contamination (>200 ppt total TEQ). This area should be isolated since the toxic potential of the sediment is very high. The approximate boundary of this zone is the area enclosed within the 150 mg/kg total PAH isopleth.

The third zone can be defined on the basis of sub-lethal biological effects and coincides with the sediment area exceeding 30 mg/kg of total PAH. This area is the area enclosed within the 30 mg/kg total PAH isopleth, and represents the area where contaminated sediment should be confined in order to minimize contaminant effects on aquatic biota. Below this concentration, there was no measurable effect on benthic organisms.

Both contaminant concentrations and biological effects are low or not apparent in those areas below 30 mg/kg, and this area would be suitable for natural remediation since existing contaminant concentrations pose little threat to biota. Comparison with an earlier study by Beak (1988) indicate that surficial sediment concentrations of total PAH have decreased since 1987, likely through deposition of cleaner material on the surface. Active deposition of new material would serve to effectively isolate the relatively more contaminated sediment in the deeper layer and would permit longer term degradation of contaminants in this area with little concern regarding potential exposure to aquatic organisms.

Conclusion

Based on the study results, a site remediation plan was developed in conjunction with the property owners. The plan calls for enclosure of the dock behind a clay barrier since seepage from the site is considered to be the source of the contamination. Outside of the clay barrier the plan calls for construction of a rock berm that encloses all of the area where sediment concentrations exceeded 150 mg/kg total PAH. Clean fill is to be placed behind this structure and is to be brought up to grade level (i.e., dry capped). The enclosed area will also contain a treatment cell that can accommodate 20,000 m^3 of sediment which is to be removed from the creosote pool and all areas where existing concentrations of total PAH are in excess of 260 mg/kg. This value is based on Ontario's soil cleanup guidelines for PAH. Soil cleanup guidelines were used since the area to be confined behind the berm will become land. At present, the plans call for biological treatment within the cell. Areas where sediment concentrations of total PAH were below 30 mg/kg would be left to remediate naturally.

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APPENDIX 5

DECISION-MAKING FOR SEDIMENT: NUMERIC BIOLOGICAL GUIDELINES

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Almost all the Great Lakes Areas of Concern have documented sediment contamination. Current sediment guidelines are based on the comparison of chemical concentrations at a site with guideline concentrations that have been established as representing a perceived safe concentration on a chemical by chemical basis. However, current practitioners generally acknowledge that chemical concentration alone is insufficient to determine sediment contamination and that biological information is also essential to determine sediment conditions. The purpose of environmental assessment and management is ultimately the maintenance of biological integrity, so it is our view that the setting of water and sediment quality objectives should include biological targets together with chemical surrogates. This approach is the basis of the sediment quality triad proposed by Chapman and co-workers (Chapman *et al.* 1992) and strongly endorsed in two International Joint Commission (1987; 1988) reviews of assessing sediment problems in the most contaminated areas of the Great Lakes. Both the sediment quality triad and the IJC promote the incorporation of laboratory and field biological assessment in identifying contaminated sediment. In both cases the use of invertebrate assemblage structure is suggested as the appropriate field component and toxicity testing as the laboratory component. This paper describes the development of numeric target values for these biological measures.

There are two basic assumptions behind these biological sediment guidelines. The first is that the effects of sediment contamination on biological processes are the primary concern, and therefore, assessment of biological effects is paramount. The second is that the complexity of the sediment matrix makes chemical concentration a poor predictor of the biological availability of contaminants.

The biological sediment guidelines incorporate the structure of benthic invertebrate communities by using predictive models that relate site habitat attributes to an expected community, and functional responses (survival, growth, and reproduction) in four sediment toxicity tests (bioassays) with benthic invertebrates using ten test endpoints. For both community structure and toxicity, guidelines have been established that allow determination of the community as either unstressed, potentially stressed, stressed, or severely stressed, and the sediment as either non-toxic, potentially toxic, or toxic.

To simplify the assessment process, the BEAST software has been developed, which incorporates the complex multivariate analysis required by this approach and presents the user with straightforward categories of sediment quality on a site by site basis. Designed for the BEnthic Assessment of SedimenT, the software automates the methodology and employs the RAISON Mapping and Analysis package from Environment Canada as a foundation. BEAST combines new methods with a simple, straightforward software user interface. The result is a powerful new tool for sediment assessment.

Reference condition concept

Until recently, the development of numeric biological targets was considered too difficult due to the temporal and spatial variability inherent in biological systems. However, over the past 15 years, methods developed in the United Kingdom (Wright *et al.* 1984) and elsewhere (Corkum and Currie 1987) have demonstrated the ability to predict the biological response in clean (or 'uncontaminated') sites using simple habitat and water quality parameters. In all these studies, the biological attributes of choice have been invertebrate assemblages. This approach allows appropriate site-specific biological objectives to be set for ecosystems from measured habitat characteristics, and also provides an appropriate reference for determining when degradation at a site due to anthropogenic contamination is occurring. The acceptance by regulatory agencies of biological water and sediment quality objectives has been slow, but is now being given serious consideration as shown by current work in Canada (Reynoldson and Zarull 1993; Reynoldson *et al.* 1995), the USA (Hunsaker and Carpenter 1990), the United Kingdom (the RIVPACS method; Wright *et al.* 1984) and Australia (Parsons and Norris 1996).

This paper describes the development of biological guidelines for sediment in nearshore fine-grained habitats in the Laurentian Great Lakes. These guidelines have been developed for invertebrate assemblages and benthic invertebrate laboratory tests using a modification of the technique developed in the UK (Wright *et al.* 1984) and now described as the reference condition concept (for more detail, see Reynoldson *et al.* 1997). The choice of invertebrate assemblages was made on the basis of the fact that these organisms are in direct contact with the contaminants associated with the sediment, and are therefore most likely to exhibit effects. The use of laboratory tests was supported to confirm that any responses observed in the field are due to sediment and not other environmental stressors. In selecting the test organisms and endpoints, it was the view that infaunal invertebrate species would be most appropriate, and that ecologically relevant (growth and reproduction) chronic, as well as acute, endpoints should be used.

Fundamental to the scientific method is the use of controls or control conditions against which results obtained under test conditions can be compared. In field comparisons, attempts are made to choose test and control sites that are as similar as possible. The variable of interest can then be manipulated, but uncontrolled variables are assumed to fluctuate. The actual choice of separate sites in the field that are similar in all aspects and that can be divided into control and experimental sites is difficult. Traditionally, this problem has been solved in aquatic studies by choosing adjacent sites in streams (i.e., upstream and downstream comparisons), dividing lakes into halves, using artificial enclosures or mesocosms, or by locating sites thought to be similar at an appropriate distance from any source of contamination. Such approaches have several problems, especially the problem of "pseudoreplication". In the reference condition approach, a wide range of minimally disturbed sites are sampled and organized by selected physical, chemical, and biological characteristics to form one or more reference conditions. These reference conditions then serve as the control(s) against which individual test sites can be compared. The notion of a reference condition is therefore really a description of best available condition.

Using the reference condition approach in developing biological guidelines for the Great Lakes involves the following steps:

Data collection. Collection of data on invertebrate assemblages, sediment toxicity tests, and habitat descriptors from reference sites that describe the broadest range of natural variation in fine-grained sediment from the nearshore of the Great Lakes must occur.

Site classification and model building. Reference sites are organized into groups with similar biological attributes based either on the composition of their invertebrate fauna or the response in the laboratory test endpoints. The characteristics of these community groups and the test endpoint ranges form the bases for the guidelines.

Predictive models are developed that relate a set of habitat attributes to the groups of sites formed from the biological data. The models are used to determine the probability of a test site belonging to individual reference site groups.

The data collection, reference site classification, and model building are required to develop the guidelines and are a one time effort. However, the models can be refined and periodically upgraded as further data are collected.

The following steps are used in the assessment of sediment quality using the biological sediment guidelines:

Selection of reference sites for comparison. A statistical technique, discriminant function analysis (DFA), with physio-chemical variables is used to determine the probability of a test site belonging to one or more of the reference groups.

Test site assessment. This is the step that defines whether the biological response at a test site meets expectation, and compares the biological attributes of the test site with the normal range observed at the appropriately matching reference sites.

In the Great Lakes study (Reynoldson and Day 1998), a large database was assembled from 312 locations in Lakes Ontario, Erie, Michigan, Superior, and Huron and analyzed to establish reference conditions. Information from each site included: the responses of four species of benthic invertebrates (*Hyalella azteca, Chironomus riparius, Hexagenia spp.* and *Tubifex tubifex*) exposed in the laboratory, the structure of the benthic invertebrate community, and selected environmental variables from the same site.

Using multivariate statistical methods, 6 community assemblages have been characterized in the Great Lakes. Using discriminant function analysis with 12 habitat descriptors, reference sites can be predicted to one of these 6 assemblages with confidence (average error rate 12%). Thus the invertebrate community at any test site in the Great Lakes can be predicted from the measurement of 12 easily and inexpensively measured habitat attributes (latitude, longitude, depth, alkalinity, pH, TN, TOC, K2O, CaO, MgO, MnO, SiO2). Assessment of the condition of the invertebrate community at a test site involves a simple comparison of the community at the test site with the communities occurring at the group of reference sites to which the test site is predicted as belonging.

The actual comparison is done by reducing the species matrix to ordination vectors. This is because 162 species have been identified in the Great Lakes, and species by species comparison is impractical. Therefore, the reference communities are described by three ordination axes and can be plotted graphically as a site "cloud" in ordination space. By plotting the test site with the reference sites "cloud", the similarity to the reference sites can be determined by using probability ellipses for the reference sites only and examining the position of the test site relative to the reference site ellipses. A site is defined as "equivalent to reference" if it is within the 90% probability ellipse, "possibly different" if it is between the 90 and 99% ellipse, "different" if between the 99 and 99.9% ellipse and "very different" if outside the 99.9% ellipse (i.e., less than a 1 in 1000 chance of error).

Determining toxicity was done in the same way, even though individual toxicity test endpoints showed little variability and single guideline values can be established for each endpoint, the overall assessment of sediment toxicity uses this multivariate approach as it permits the integration of multiple endpoints.

Cornwall

Twelve sampling sites were selected to assess the potential biological effects of sediment associated contaminants. Nine sites were located within depositional areas investigated in 1994, two sites (175, 179) within a deposit north of Cornwall island, and one site (167) at a boat launch deposit. In 1977, the IJC identified this part of the St. Lawrence River as an Area of Concern based upon input from the Ontario Ministry of the Environment. Restrictions to beneficial use included possibly impaired benthic invertebrate communities and restrictions on dredging because of sediment contamination (Dreier *et al.* 1997).

The National Water Research Institute (NWRI) of Environment Canada, with the support of the Cornwall RAP team and Ontario Region of Environment Canada, conducted sampling of the sediment in Cornwall in October 1997 from which data were used in assessment of community structure and sediment contamination with biological sediment guidelines developed by NWRI and Ontario Region of Environment Canada (Reynoldson and Day 1998).

Invertebrate Community Structure. All 12 sites were predicted to reference Group 2 based on the habitat attributes, with the probability of group membership ranging from 51.5% (site 175) to 82.0% (site 127).

Reference Group 2 is characterized by the fingernail clam *Pisidium casertanum* and the amphipod *Diporeia hoyi*, and this reference group represented more oligotrophic conditions (Reynoldson and Day 1998). Nine taxa were common (>50% occurrence) at the reference sites. Of these, all but one, the tubificid worm *Potamothrix vejdovskyi*, was found at the Cornwall sites. The occurrence of 120 genera at the 39 reference sites comprising Group 2 was compared with the 12 test sites sampled in Cornwall. Two very simple descriptors of community structure are taxa richness and total abundance. The range observed at the reference sites is shown in Table 1 together with the results from the Cornwall sites. These data show the overall diversity and abundance to be well within the range observed at reference sites and a general trend to greater diversity and abundance. The results of the multivariate analysis are summarized in Table 1. Four sites (127, 164, 175, 179) were outside the 90% probability ellipse, and none are outside the 99% ellipse. The 90% ellipse is defined as an area where sites may be considered as different to the reference sites, with a Type 1 error of 10%. The sites showing possible stress all have high diversity and abundance.

Table 1. Summary of taxonomic composition of benthic invertebrates at Group 2 reference sites and 12 Cornwall test sites (Occurrence at reference sites is based on percentage of those sites at which a taxon was present; abundance is expressed in terms of numbers per 34.2 cm^2)

Site	Taxa richness No. of genera mean (SD)	Total abundance No. per 34.2 cm^2 mean (SD)	Abundance and occurrence of: Procladius	Abundance and occurrence of: Pisidium	Abundance and occurrence of: Piona	BEAST assessment community
Reference (n=39)	20.5 (9.8)	60.6 (46.1)	1.94 (84.6%)	6.24 (82.1%)	0.0 (0.0)	
105	19	38.25	5.2	4.6	1	Unstressed
109	19	35.2	7.2	4.2	0.2	Unstressed
117	20	32.4	6.8	4.4	0.8	Unstressed
127	24	98.6	3.8	0.6	1.2	Possibly stressed
128	37	106.4	2.6	12.6	0.6	Unstressed
131	20	51.8	5.8	10	0.8	Unstressed
132	25	48	4.4	8	0	Unstressed
156	26	49.8	2.2	3.6	0	Unstressed
164	17	30	3.6	0	1.2	Possibly stressed
167	28	74	4.8	9.4	0.8	Unstressed
175	24	81.6	11	0	0.4	Possibly stressed
179	26	97.8	14.4	0	0.6	Possibly stressed

Sediment toxicity. The results from the 10 test endpoints showed only two endpoints to be below the warning levels derived from the reference sites. These are both related to reproduction in the tubificid oligochaete *Tubifex tubifex*. Five sites (105, 127, 156, 164, 167) had a reduced rate of cocoon hatching, suggestive of impairment in the embryogenesis of the worm eggs. All five sites, not unexpectedly, had reduced young also. However, a further two sites (117 and 128) had reduced young per adult. The other three species show no evidence of sediment toxicity.

Comparison of community and toxicity data. The assessments of community and toxicity effects are summarised in Table 2. In addition, the habitat attributes that either exceed Ontario sediment criteria (Persaud *et al.* 1992) or are outside the range observed at the reference sites are also identified.

In general there is no strong evidence for either impaired invertebrate communities or any associated sediment toxicity. While several variables exceed the OMOE low effect level criteria, this also occurs at reference sites. At six sites, Hg exceeded the Severe Effect Level and at Site 109, Zn also exceeded the severe effect concentration (Table 2). However, this site and three of the other six showed no indication of either toxicity or impaired community structure. There is some effect on reproduction of the worm *Tubifex*. This may account for the absence of the worm *P. vejdovski*, a species present at many (53%) of the reference sites. However, immature worms were found at all but one site (164) and the apparent absence of *Potamothrix* is likely due to the absence of identifiable mature animals. In conclusion, these data do not indicate a sediment contamination problem associated with the samples taken form the Cornwall area.

Table 2. Summary of sediment quality based on invertebrate community structure, sediment toxicity, and sediment chemistry

Site	BEAST Assessment		Variables Exceeding OMOE Sediment Criteria		Variables > 2 SD than reference
	Community	Toxicity	Low	Severe	
105	Unstressed	Possibly toxic	TP, TOC, Cr, Ni, Cu, Zn, Pb, Hg	Zn	
109	Unstressed	Non toxic	TP, TOC, Cr, Ni, Cu, Zn, Pb	Zn, Hg	Cu, Zn, Pb
117	Unstressed	Possibly toxic	TP, TOC, Cu, Zn, Pb, Hg		Zn
127	Possibly stressed	Possibly toxic	TP, TOC, Cu, Zn	Hg	Gravel, 25% PS
128	Unstressed	Non toxic	TP, TOC, Cu, Zn	Hg	
131	Unstressed	Non toxic	TP, TOC, Cr, Ni, Cu, Zn, Pb	Hg	Cu, Zn
132	Unstressed	Non toxic	TP, TOC, Cr, Ni, Cu, Zn, Pb	Hg	
156	Unstressed	Possibly toxic	TP, TOC, Cu, Zn, Hg		
164	Possibly stressed	Non toxic	TP, TOC, Cr, Ni, Cu, Zn, Pb	Hg	Cu, Zn
167	Unstressed	Possibly toxic	TP, TOC, Ni, Cu, Zn, Hg		
175	Possibly stressed	Non toxic	TP, TOC, Cr, Ni, Cu, Zn		
179	Possibly stressed	Non toxic	TP, TOC, Cr, Ni, Cu, Zn		

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APPENDIX 6

ECOLOGICAL RISK ASSESSMENT APPLIED IN THE SAGINAW RIVER/SAGINAW BAY

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Saginaw Bay is a relatively large (2,960 km^2) southwestern extension of Lake Huron, located in the east central portion of Michigan's lower peninsula. The Saginaw Bay watershed drains 22,557 km^2, including portions of 22 counties and 15% of Michigan's total land area. Saginaw Bay is regarded as one of the prime walleye fishing and waterfowl hunting areas in the Great Lakes.

Industrial facilities and wastewater treatment plants on the Saginaw River have released PCBs (polychlorinated biphenyls) and related compounds into the Saginaw River for decades. These releases have decreased in recent years as a result of various controls, but sediment remains contaminated and the PCBs released have caused environmental damage to the ecosystem of the Saginaw River and Bay. The bay also drains into Lake Huron, so contaminants pose far reaching risks if not contained and halted.

Contamination has impacted fish and wildlife resources in the Saginaw River and Bay, resulting in advisories against human consumption of all species of fish in the river and many species of fish in the bay. Also, bald eagle reproduction is significantly lower in these areas than found in less contaminated areas.

The U.S. Fish and Wildlife Service, the State of Michigan, and the Saginaw Chippewa Tribe worked as co-trustees in conducting a Natural Resource Damage Assessment for the Saginaw River and Bay. In the assessment process, the trustees evaluated injuries to trust resources as well as restoration actions that could restore the ecosystem functions and compensate the public for injuries to their natural resources caused by the release of PCBs.

In the injury assessment process, the trustees selected species of concern and endpoints to evaluate, and then calculated target concentrations of PCBs in the sediment. Bald eagles and fish-eating birds were selected for evaluation because they are at the top of the food chain and are therefore highly exposed to PCBs. In addition, many published reports were already available on the effects of PCBs on fish-eating birds in Saginaw Bay and at other Great Lakes sites, in both contaminated and reference areas. Mink were selected because they are also fish-eaters, and because mink are highly sensitive to PCBs and related compounds. Studies in which ranch mink were fed fish from Saginaw Bay had clearly demonstrated that mink reproduction could be impaired by such a diet. Finally, sport fish were selected for analysis because of past and existing fish consumption advisories for PCBs and because of the value that the public places on having fishable waters from which they can eat the fish.

The endpoints selected for evaluation for the birds were reproduction and recruitment. Decreased hatching and fledgling success were documented in the field, and concentrations of PCBs were measured in tissues and prey items. A steady-state bioaccumulation model was used to calculate a No Observable Adverse Effect Level (NOAEL) in whole forage fish from a NOAEL value in bird eggs from the literature. Site-specific information was then used to estimate sediment concentrations which correspond to the NOAEL in forage fish.

The endpoint selected for evaluation for the mink was reproduction. Laboratory data demonstrated effects in the laboratory and anecdotal information indicated a reduction in populations in the area (decreased ratio of incidental mink capture to muskrat capture by trappers). An oral dose model was used to calculate a NOAEL in the fish component of the mink diet from an oral dose NOAEL from the literature. As for the birds, site-specific information was then used to estimate sediment concentrations which correspond to the NOAEL in forage fish.

The endpoint for sport fish was target tissue concentrations low enough such that consumption advisories for PCBs could be removed. Site-specific information was used to estimate sediment concentrations corresponding to target tissue concentrations in sport fish fillets.

Sediment thresholds were compared to spatial patterns of PCB concentrations in Saginaw River and Bay. Thresholds were exceeded in surficial sediment in many areas of the river and the inner part of the bay. A few thresholds were exceeded in the outer bay. The patterns of PCB concentrations with depth indicated that inputs to sediment in the river have decreased recently, but that PCBs in the bay are at greater concentrations at the surface than at depth. The sediment of the Saginaw River contains a significant mass of PCBs, which has the potential to be released downstream. Thus, the river continues to be a source of PCBs to the bay.

The trustees decided that it would not be practicable to remediate sediment to all threshold levels everywhere that they occur. Without field-proven methods for *in situ* reduction of PCB concentrations to the sub- mg/kg range, removal and capping were the options considered. Capping was not a viable option for the river because of its shallow depth, regular dredging, extensive recreational and commercial navigation, and trend toward shoreline development with dredging and bulkheading. The trustees concluded that removal (or capping) of large areas of sediment (hundreds of square kilometers) in the bay was likely to cause a disproportionate destruction of habitat. The trustees selected removing the largest mass of PCBs practicable from the river and compensating the public for past and continuing injuries to natural resources as their goals in the negotiations with responsible parties.

The trustees recently reached a negotiated settlement for natural resource damages with General Motors Corporation and the cities of Bay City and Saginaw. The settlement provides for substantial cleanup of river contamination and for protection and restoration of fish and wildlife habitats in the Saginaw River and Bay. The settlement is one of the largest achieved by the Department of the Interior as the lead federal agency to recover natural resource damages.

The settlement will result in the removal of 264,000 cubic meters of contaminated sediment, or about 90 percent of the mass of PCBs in the lower river (Table 1). Dredging is expected to begin in 2000. Although not all risk will be removed, experts believe that additional restoration dredging would significantly increase the physical injury to habitat while providing little additional removal of PCBs. The settlement also provides for acquisition, restoration, and protection of more than 680 hectares of habitat, as well as restoration of acquired land that has been drained previously for agricultural use. Restoration will also include fish habitat between Saginaw Bay and Tobico Marsh, and for the Green Point Environmental Learning Center in Saginaw. Boat launches and nature viewing opportunities will be provided at two sites on the river in Bay City and at one site on the bay in Essexville to compensate the public for injuries to the State's resources. A restoration account will be funded by the responsible parties so that the trustees can monitor recovery of the system and make informed decisions on balancing additional habitat restoration projects, additional cleanup activities, and continued monitoring.

Table 1. Components of the Saginaw Natural Resource Damage Assessment Settlement

Component	Description	Cost
Removal of contaminated sediment from deposits in the Saginaw River	• 264,000 cubic meters will be removed and placed in an Army Corps disposal facility • dredging will meet environmental performance criteria • dredging will be managed by the Corps with oversight and responsibility by the Service and the State • project will take 1-2 years • dredge design has optimized to remove 90% of the mass of PCBs remaining in the lower river	$11,150,000
Land acquisition to restore habitat and to protect existing habitat from development	• 680 hectares • land to be owned and managed by the Michigan Department of Natural Resources, the Saginaw Chippewa Tribe, and the Service's Shiawassee National Wildlife Refuge • land selected based on long-lasting ecosystem management objectives, relationship to existing public lands, and restoration of resources injured by PCBs	$6,700,000
Restoration on acquired land	• restoration of acquired land which was previously drained for agriculture • emphasis on coastal wetlands and lake plain prairie	$1,000,000
Tobico Marsh restoration	• restoration of water flow between Saginaw Bay and Tobico Marsh • emphasis on restoration of northern pike and yellow perch spawning	$500,0000
Green Point Environmental Learning Center activities	• restoration of lost services because of injury to natural resources • emphasis on services important to area residents	$520,000
Green Point Environmental Learning Center leases	• two 99-year leases of Green Point Environmental Learning Center • includes interpretive center building and 32 hectares of riparian and upland habitat	not quantified
Restoration Account	• funds in court registry account to be managed by Trustee Council • emphasis on monitoring recovery and implementing additional restoration projects • builds on existing assessment data	$3,100,000
Recreational/educational areas	• three areas with boat launches, nature-viewing opportunities, interpretive signs • Bay City will operate and maintain two of the areas and MDNR will own and operate the third	$3,500,000
Cost Recovery	• Service to receive $0.8 million for past assessment and future oversight costs • State to receive $1.2 million	$2,000,000

APPENDIX 7

THE APPLICATION OF HUMAN HEALTH RISK ASSESSMENT TECHNIQUES AT SEDIMENT CONTAMINATED SITES UNDER THE SUPERFUND PROGRAM

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To evaluate the potential health effects from sediment contaminated sites, the U. S. Environmental Protection Agency (EPA) Superfund program uses a Remedial Investigation and Feasibility Study (RI/FS) process to characterize the nature and extent of risks posed by uncontrolled hazardous waste sites and aid in developing and evaluating remedial options. The human health evaluation process is an integral part of the remedial response process defined by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980, the Superfund Amendments and Reauthorization Act (SARA) of 1986, and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulation that implements CERCLA. Ecological risk assessment and the role of stakeholders in the RI/FS are beyond the scope of this presentation.

Project scoping. The main objectives of project scoping are: to identify site related decisions, to determine the type (including quantity and quality) of data needed, to define data Quality Assurance/Quality Control (QA/QC) objectives, and to define the site related type and extent of investigation. The Remedial Project Manager and team members collaborate to evaluate the possible impacts of site releases on human health resulting in a site-conceptual model that qualitatively considers available information (e.g., historical, previous site investigations, etc.) to determine the source of contamination, potential pathways of exposure, and populations potentially impacted. The conceptual model is refined and updated with new information throughout the RI/FS process.

The need for developing site-specific sediment fate and transport models are also evaluated during scoping so that model data collection requirements are met. Data at sediment sites may include: hydrology, water quality and aquatic resources, waterbody physical characteristics, nature and extent of contamination, and bioaccumulation. Models may be used to evaluate the extent of contamination, the potential for migration of contaminated sediment over specified periods of time, and the uptake of sediment contaminants through the food chain.

Risk assessment. Risk assessment originally defined by the National Academy of Sciences (1983) involves: hazard identification, toxicity assessment, exposure assessment, and risk characterization. Risk assessment is used throughout the RI/FS process to develop the baseline risk assessment to evaluate risks in the absence of remediation, to refine preliminary remediation goals, and to evaluate remedial alternatives. Risk assessment provides a framework for evaluating and organizing collected information and comparing the relative risks of individual chemicals and routes of exposure.

Superfund risk assessments are designed to evaluate current and potential risks to the Reasonably Maximally Exposed Individual. Both cancer and non-cancer health effects for adults and children are evaluated. The baseline risk assessment and preliminary remediation goals are developed during the Remedial Investigation while the Feasibility Study refines the preliminary remediation goals and evaluates remedial alternatives.

Hazard identification. This involves evaluating collected data against the QA/QC objectives and selecting appropriate data for the risk assessment. The primary sediment data collected includes concentrations of chemicals in the sediment and water column, and the fate and transport of these contaminants within the aquatic environment, especially where the contaminants may bioaccumulate through the food chain. The media-specific chemicals of potential concern are characterized based on their potential to cause either cancer or non-cancer health effects, or both.

Toxicity evaluation. This involves evaluating EPA toxicity databases and sources to identify cancer and non-cancer oral and inhalation toxicity values. The databases in order of importance are: the Integrated Risk Information System (IRIS); EPA's consensus review database of over 500 chemicals; the Health Effects Assessment Summary Tables published by EPA's Office of Solid Waste and Emergency Response, including information on chemicals not available on IRIS; and EPA's National Center for Environmental Assessment provisional toxicity values.

Carcinogens are evaluated based on the Weight of Evidence and potency. The Weight of Evidence qualitatively assesses whether a chemical is known to cause cancer in humans, likely to cause cancer in humans based on animal data and limited human data, or not likely to cause cancer in humans. The chemical-specific potency is based on the cancer slope factor - a plausible upper bound estimate of the probability of a response per unit intake for a chemical over a lifetime. The slope factor combined with exposure information is used to estimate an upper bound probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen over a lifetime.

Non-cancer health effects are evaluated using a Reference Dose (RfD) for oral and Reference Concentration (RfC) for inhalation. The RfD and RfC are defined as an estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure level for the human population, including sensitive subpopulations that is likely to be without an appreciable risk of deleterious effects during a lifetime. Comparison of the exposure dose over a specific time frame to the RfD indicates a concern for potential non-cancer health effects.

Chemicals lacking toxicity are qualitatively discussed in the risk characterization. The discussion addresses the potential impacts of the missing toxicity data on the calculated risks.

Exposure assessment. This estimates the type and magnitude of chemical exposure from chemicals of concern present at or migrating from the site. The results from the exposure assessment are combined with chemical-specific toxicity information to characterize potential risks and hazards.

At sediment contaminated sites, routes of exposure may include: ingestion of contaminated river water, inhalation of chemicals volatilizing from sediment, recreational exposures (incidental ingestion of sediment and dermal contact with sediment and water), and ingestion of fish. Usually the primary risk is from ingestion of fish where chemical specific concentrations from sediment bioaccumulate.

Exposure from fish consumption involves determining the fish chemical concentration, the daily amount of fish ingested, the frequency of fish obtained from a specific source, and the duration of exposure. Fish consumption data may be obtained from site-specific creel surveys, national or regional surveys with data on the specific fish species for the site, surveys of licenses, angler fishing practices and consumption patterns, and surveys of anglers at specific fishing spots. Duration data may be obtained from census data or local mobility information.

The result of the exposure assessment is a calculated Chronic Daily Intake. The calculated dose may be adjusted for children and adults including modifications to the exposure variables that reflect the unique physiological characteristics associated with age. Dose information is combined with the cancer slope factor and the RfD, respectively, to calculate risk and hazard.

Risk characterization. This presents the calculated risks and hazards for the reasonably maximally exposed individual for each pathway and chemical, and across chemicals and pathways. A discussion of the uncertainties for all components of the risk assessment are also included in the risk characterization. The goal is to provide this information reflecting transparency in the decision-making process, clarity in the communication, consistency with other assessments, and reasonableness. The risk characterization serves as the bridge

between the assessment of potential risks from the site and the risk management decision concerning the potential need for remedial actions.

Remedial actions. Risk assessment results are used by the Project Manager to determine the need for further action based on criteria in the National Contingency Plan. The Feasibility Study identifies the remedial action objectives for contaminants and media of concern, potential exposure pathways, and preliminary remediation goals including compliance with Applicable or Relevant and Appropriate Requirements (ARARs). Risk assessment is used to determine whether the goals protect public health.

Analysis of remedial actions includes assessment of the extent of contamination, ARARS, chemical-specific environmental fate and toxicity information, and engineering analysis. The remedial action alternatives and associated technologies are screened to identify those that are effective for the contaminants and media of interest at the site. The information developed in these two activities is used in assembling technologies into alternatives for the site as a whole, or for a specific portion of the site.

In determining the remedial site actions, each alternative is assessed against specific evaluation criteria and the results arrayed to allow comparisons between alternatives. The nine evaluation criteria include:

- Overall protection of human health and the environment
- Compliance with ARARs
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through the use of treatment
- Short-term effectiveness
- Implementability
- Cost
- State acceptance
- Community acceptance.

The first two criteria are threshold determinations and must be met before remedy selection. The next five criteria are balancing criteria and the last two criteria are modifying criteria. Risk information is important in the analysis of effectiveness and permanence of a remedial action by assessing residual risk after the response objectives were met. The alternatives are also evaluated with respect to the potential effects on human health during implementation of the remedial action and the length of time until protection is achieved.

Disclaimer:

The views presented in this abstract are those of the author and do not necessarily reflect the views or policies of the United States Environmental Protection Agency.

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APPENDIX 8

U.S. ARMY CORPS OF ENGINEERS DREDGED MATERIAL EVALUATION AND ASSESSMENT PROCEDURES

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Abstract

The U.S. Army Corps of Engineers has statutory authority to regulate the disposal of dredged material in waters of the United States under the Clean Water Act and in the oceans under the Marine Protection, Research, and Sanctuaries Act. In carrying out this authority, the Corps has conducted over $100 million of research on dredging and the disposal of dredged material.

As required by domestic law and the International London Dumping Convention, the suitability of dredged material for open-water disposal is determined by an ecological effects-based approach rather than consideration of the concentrations of chemical contaminants in the sediment. The rationale for this is that dredged material is a complex mixture of many substances whose bioavailability and potential interactions cannot be predicted merely on the basis of the concentrations of the chemicals of concern.

This effects-based approach uses physical, chemical, and biological assessments, and consists of contaminant mobility/bioavailability modeling; acute toxicity bioassays, which address the benthic and water column environments; and contaminant uptake bioassays, which provide information on the potential for bioaccumulation. Risk assessment procedures are available for the more difficult projects. The procedures followed by the Corps in accordance with U.S. Environmental Protection Agency regulations have significant potential for the evaluation of sediment in general. However, it must be recognized that the disposal of dredged material is usually an instantaneous event (hopper, dredges, dump scows), or very short-term (hydraulic pipeline). Thus, acute, rather than chronic effects, are of primary concern. Chronic/sub-lethal tests will be available in the near future.

For further information on environmental effects of dredging, please see "Environmental Effects of Dredging Program Technical Notes" under "Publications" on the following web site: http://www.wes.army.mil/el/dots

TESTING AND EVALUATION PROCEDURES FOR GREAT LAKES DREDGED MATERIAL EVALUATIONS DEVELOPED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY AND THE U.S. CORPS OF ENGINEERS

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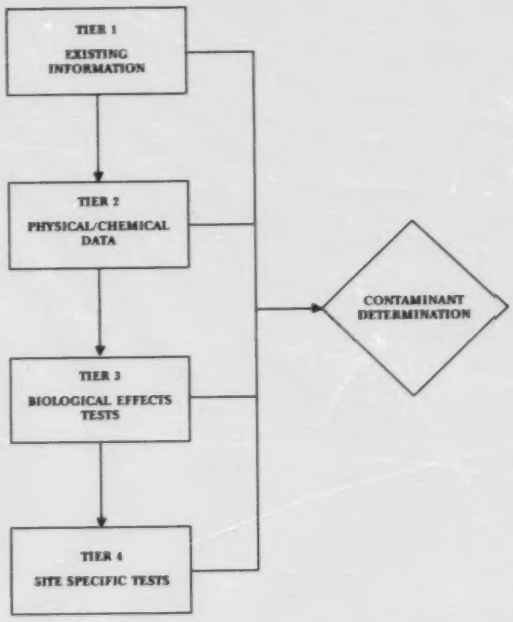
The U.S. Environmental Protection Agency (EPA) and U.S. Army Corps of Engineers (Corps) have developed a regional testing manual for evaluating potential impacts of contaminants from dredged material proposed for discharge to the Great Lakes, connecting channels, and tributaries. This manual is intended to be used as a decision-making tool for dredge and fill permits issued by the Army Corps of Engineers, or States or Tribes where delegated, under Section 404 of the Clean Water Act. This guidance is consistent with the technical framework developed by the Corps and EPA for evaluating the environmental effects of dredged material management alternatives (USACE/USEPA 1992).

The Great Lakes Dredged Material Testing & Evaluation Manual utilizes a tiered approach for testing and evaluation, which is consistent with the national manuals developed for testing dredged material proposed for discharge in inland waters (USEPA/USACE 1998) and ocean disposal (USEPA/USACE 1990). This tiered approach is also generally consistent with the "Guidelines for Project Evaluation" developed by the International Joint Commission (IJC 1982).



The objective of the tiered testing approach is to make optimal use of resources in generating the information necessary to make a contaminant determination, using an integrated chemical, physical, and biological approach. To achieve this objective, the procedures in this manual are arranged in a series of tiers with increasing levels of intensity. The initial tier uses available information that may be sufficient for completing the evaluation in some cases. Evaluation at successive tiers requires information from tests of increasing sophistication and cost.

The most logical and cost efficient approach is to enter Tier 1 and proceed as far as necessary to make a determination. There are two possible conclusions that can be made at each of the first three tiers:

1. Available information is not sufficient to make a contaminant determination, or
2. Available information is sufficient to make a contaminant determination.

Where information is sufficient (conclusion 1), one of the following determinations may be reached:

- The proposed discharge will not have unsuitable, adverse, contaminant-related impacts, or
- The proposed discharge will have unsuitable, adverse, contaminant-related impacts

Tier 1 compiles existing information about the potential for contamination in the proposed dredged material. Disposal operations that are excluded from testing or have historic data sufficient for the contaminant

determination may proceed to a determination without additional testing. The manual identifies sources of historical sediment data, lists industries and activities associated with sediment contamination, and provides examples of cases where testing is and is not needed.

Tier 2 evaluates the potential impacts of the proposed discharge on water column and benthic environments using sediment physical and chemical data collected for this tier, and applied with computer models to project worst-case conditions for water quality impacts and bioaccumulation. The manual provides detailed guidance on acceptable analytical procedures for physical and chemical analysis of selected parameters. Based on the results of Tier 2 evaluations, additional testing may be reduced or eliminated.

Tier 3 evaluates the potential impacts of the proposed discharge on water column and benthic environments using effects-based biological testing. The manual presents recommended procedures for biological-effects tests developed specifically for use in the Great Lakes Basin. The features of these tests are summarized below. Not all tests endpoints have been approved for Tier 3 application.

Species	Medium	Endpoint(s)	Test Duration (days)
Daphnia magna	Elutriate	Survival/Survival and Reproduction	2/21
Ceriodaphnia dubia	Elutriate	Survival/Survival and Reproduction	2/7
Pimephales promelas	Elutriate	Survival/Survival and Growth	4/7
Chironomus tentans	Sediment	Survival and Growth	10
Hyalella azteca	Sediment	Survival and Growth	10
Lumbriculus variegatus	Sediment	Bioaccumulation	28

Tier 4 is only entered if the information provided by Tiers 1 through 3 is not sufficient to make a contaminant determination. The procedures used in Tier 4 are keyed to site specific issues not resolved by the standardized procedures of earlier tiers. It is intended that very few situations will require a Tier 4 evaluation.

With this tiered testing structure, it is not necessary to obtain data for all tiers to make a contaminant determination. It may also not be necessary to conduct every test described within a given tier to have sufficient information for a determination. The underlying philosophy is that only that data necessary for a determination should be acquired.

The Great Lakes Dredged Material Testing & Evaluation Manual is available to download from the following web site: www.epa.gov/glnpo/sediment/gltem/

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APPENDIX 9

1994/1995 ST. CLAIR RIVER SEDIMENT PROGRAM DEFINING SPATIAL EXTENT AND ENVIRONMENTAL CONDITIONS

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Introduction

Results of an integrated sediment study conducted by the Lambton Industrial Society (LIS) in 1994 and 1995 demonstrated continuing concerns with contaminated sediment and associated effects on organisms exposed to the sediment. The project hypothesis "Contaminated sediment is causing deleterious impacts on the aquatic biota of the St. Clair River" was accepted for specific locations in each of the three study zones.

The benthic community structure at 17 of 28 sample sites could not be differentiated from reference sites upstream and downstream of three study zones. Nearshore sites in Zone 3 were classified as moderately impaired, and specific sites in Zones 1 and 2 were slightly impaired. No sample locations were found to be degraded.

The study established an increase in the number of taxa of benthic macroinvertebrates relative to earlier studies at every site, an indication of continuing recovery of sediment quality.

Rationale

Extensive monitoring of the St. Clair River has been ongoing since the mid 1950s. Early studies found a degraded environment characterized by poor water and sediment quality. Subsequent studies indicate a trend of continuing improvement, attributed to reductions in contaminant loadings from industries and municipalities located along the Ontario side of the river. Using the most recent studies, the St. Clair Remedial Action Plan identified the three sediment zones as "priority 1" areas for study due to sediment contamination and impacts on the benthic macroinvertebrate community.

The LIS initiated a study in 1994 to further define the spatial extent of impairment and sediment quality conditions in these three zones. The project hypothesis "Contaminated sediment is causing deleterious impacts on the aquatic biota of the St. Clair River" was adopted.

Methodology

An assessment of the biologically active surficial sediment using an integrated study design was used. The study incorporates bulk sediment chemistry analysis, benthic macroinvertebrate assemblage assessment, and laboratory toxicity tests using a variety of aquatic test species.

Synoptic samples were collected at each of 31 sites using a ponar dredge. Samples were collected at midshore locations in the three study zones in the Spring of 1994, along with nearshore and offshore samples in Zone 3. Additional nearshore and offshore samples were collected in Zone 2 in the Spring of 1995. Reference samples were also obtained from locations near the head of the river, Sarnia Bay immediately upstream of study Zone 1, and downstream of Zone 3 in 1994.

Chemical analyses were completed for compounds for which Ontario has established biological effects criteria, or have been identified as a sediment quality concern by the St. Clair River RAP, or are associated with the prediction of a normal benthic community.

Sediment toxicity tests used in this study included a 21 day fathead minnow survival test, a 21 day mayfly larva survival and growth test, a midge larva 10 day survival and growth test, and an aquatic worm 28 day survival and reproductive success test.

Results and analysis

Field observation. Oil droplets were visible in all Zone 1 and 2 and some Zone 3 samples. Petroleum odors were also evident in these samples. Sewage fungi were found on the surface of all Zone 1 samples. Aquatic plants were present in all samples except for several from Zone 3. Hydrocarbon contamination was observed at reference stations 2 and 3.

Sediment chemistry. Chemical analyses showed that sediment from all stations, including the reference sites, exceeded Lowest Effect Levels (LEL) identified in the Provincial Sediment Quality Guidelines (PSQG) for several compounds. The LEL is considered to be the level of contamination that is tolerable by most benthic organisms. LELs were exceeded at one or more stations for PAHs, individually as well as total PAH, hexachlorobenzene, PCBs, arsenic, cadmium, copper, lead, mercury, nickel, zinc, total organic carbon, and total Kjeldahl nitrogen. Pesticides were below detection limits at all sites.

Hexachlorobenzene at 8 stations, and mercury at 11 stations exceeded the PSQG Severe Effect Levels (SEL). The SEL is the concentration at which a pronounced disturbance of the benthic organisms could be expected. Concentrations of hexachlorobenzene and mercury were lower than historical levels at most locations.

Statistical analysis of the physical/chemical data found that variation among the sites could be attributed to three principal components. The first identified organically or nutriently enriched stations in areas of reduced current velocity and increased deposition. The second identified stations with elevated levels of chlorinated organics, PCBs, chromium, mercury, and zinc, all in Zone 1. The third identified an offshore station in Zone 2 where the highest PAH concentrations were recorded.

Laboratory toxicity testing. Sediment from 27 of the 31 sample sites demonstrated toxicity to at least one species. No location demonstrated toxicity to all four test species. All reference sites showed a toxic (acute or sub-lethal) response in one test species, a typical result of sediment toxicity observed even in pristine areas of the Great Lakes.

Fathead minnows demonstrated the greatest acute toxicity to sediment from many stations within Zones 1 and 2. A partial acute response by mayfly larvae to sediment from two Zone 3 stations, and to midge larvae exposed to one Zone 3 sediment also occurred.

The response by fathead minnows, given their ecological niche, suggests that contaminants are leaching from the sediment into the water during the static toxicity test. This requires further study, as the test condition differs markedly from *in situ* conditions where the water is constantly refreshed.

The worm test species, *Tubifex*, demonstrated no acute toxicity to sediment from any test site, but had the highest number of chronic responses based on reduced reproduction. This increased sensitivity is likely related to the intimate contact with and ingestion of sediment-associated anthropogenic toxicants. Although the worms were the most sensitive species to test sediment in laboratory conditions, the *in situ* benthic community at several of the same stations was dominated by worms. It is likely that an adaptation to in-place contaminants has occurred in the resident worm populations, many of which are not *T. tubifex*.

Efforts to relate sites statistically on the basis of toxicity responses alone separated the fathead minnow results from those of the three benthic organisms. Sites at which samples of sediment were toxic to fathead minnows tended not to be toxic to benthic organisms, and where toxicity to benthic organisms was evident, fathead minnows showed no response.

Benthic community assessment. The benthic macro-invertebrate community assessment showed an increase in the number of taxa present for all stations within all three zones, compared to studies completed in 1985 and 1990.

Midge and worm taxa together accounted for 73.2-98.0% of the organisms present. Worms dominated at most of the locations described as degraded or "priority 1" in previous studies.

Two well recognized statistical approached to describing variability among stations based on the benthic macro-invertebrate assemblage were applied to the study results.

Principal component analysis (PCA) identified very little variation, separating only two Zone 3 nearshore stations into a grouping distinct form the others, due to the numerical dominance of immature worms at these stations. Reference stations were included in the general grouping.

The lack of variability identified by PCA analysis may be due to a number of factors, including:

- An inadequate number of stations to differentiate the physical/chemical features of the study zones
- Changes in benthic community may be small, requiring a larger sample size to identify variability
- The stations represent a heterogenous environment, as indicated by the wide scatter of the station scores
- No difference exists between the three study zones and the reference stations
- An inability to determine an effect using benthic community assemblage

An alternative statistical examination of results did identify variability. Cluster analysis identified the likely presence of four distinct clusters of sites. Two clusters could be distinguished from the reference sites. The first included stations from Zones 1 and 2 that were also identified in statistical analysis of physical/chemical parameters as being organically rich depositional zones. The second included stations within Zone 3 numerically dominated by worms. Stations in these two clusters include the stations identified in the 1990 study as degraded, as well as additional stations in close proximity to those stations.

All other stations, which were indistinguishable from reference stations, had a reduced number of worms, relatively more midge larvae, and a higher representation of more pollution sensitive species.

Classification of degree of impairment of an area based on benthic assemblage is subjective; however, some conclusions have been drawn. Based on classifications used in the 1985 and 1990 studies, the cluster of stations within Zone 3 that were distinguished from the reference stations remain moderately impaired. All other stations, including sites within each of the three study zones, were indistinguishable from the reference areas. The benthic assemblage in these locations is similar to benthic assemblages outside the study zones.

If it is assumed that the reference stations adequately reflect the benthic assemblage that would be present within the three study zones had chemical contamination not been a concern, then the stations that differentiate from the reference stations likely do so due to chemical contamination within the sediment or in the water column.

Definitively differentiating benthic communities would require incorporating an increased number of reference stations to improve confidence in defining a typical benthic assemblage for areas not affected by chemical contamination. Adapting an approach by Reynoldson (Reynoldson *et al.* 1995) to assessment of sediment in the open waters of lakes could be accomplished by incorporating reference sites from the U.S. side of the river. Work by Harris (1996) suggested an increasing number of taxa with downstream distance, on both sides of the river.

Integration of results

A fully integrated study requires that the three components of the study be interpreted simultaneously. Chapman *et al.*, (1992) provides an approach for integrating the chemical analyses, laboratory toxicity results, and benthic community assemblages.

- The following conclusions are drawn following this approach:
- Contamination is having an effect at all study sites, including the reference sites.
- At four sites, the interpretations "contamination is not biologically available" or "alteration is not due to toxic chemicals" apply. While LEL or SEL levels were exceeded at these sites, no responses were identified in laboratory toxicity tests, and the benthic community was not altered.
- At 20 sites, "chemicals are stressing the system" - some chemicals exceeded LEL or SEL values, and there was a limited toxicological response.
- At 7 sites, there was "strong evidence of pollution induced degradation from sediment".

The conclusion that "chemicals are stressing the system" at the reference sites is based on LEL exceedances and limited toxicity responses, suggesting that these stations are inappropriate as reference stations, or that the interpretation is conservative. Some workers have found that there are variable toxicity responses in areas within the Great Lakes considered to be healthy or pristine. Bailey *et al.* (1995) concluded that "there is a range of unimpaired communities with associated levels of toxicity, rather than a single, defined, healthy ecosystem." Krantzberg (1994) states that there must be an understanding of the "expected degree of variation in natural communities." A wider selection of reference sites in the St. Clair River is required to resolve these issues.

Interrelationships. A number of statistical approaches were applied to determine overall relationships between and among the three study components.

A Mantel's test comparison of the three data matrices was completed. Mantel's test indicated that each component of the integrated study was independent of the others. No relationship was established between chemical analyses and either sediment toxicity results or benthic community structure, nor between sediment toxicity results and benthic community structure. Benthic community structure and laboratory toxicity results were not related to chemical analyses, nor were toxicity results and benthic community structure related.

Attempts to relate toxicity responses to physical/chemical parameters statistically did not produce robust associations, tending to reflect the naturally occurring physical and chemical parameters rather than anthropogenic parameters. Several contaminants showed weak associations with increases in toxicity, including aluminium, cadmium, copper, zinc, 2,4,5-trichlorobenzene, hexachlorobenzene, octachlorostyrene, and pentachlorobenzene. Others showed no detrimental association with toxicity for any test species - PCBs, total PAHs, and oil and grease.

Presentation of results

Three methods of summarizing integrated results of the study were used.

Detailed summary tables were prepared to interpret data for each site, ie., "chemicals are stressing the system" using the format discussed by Chapman *et al.* (1992).

Data were also presented visually, linking results at each sample location to its mapped location. Each site was represented by a color-coded pie chart in which the three study elements - chemistry, toxicity, and benthic community structure - are given equal areas. The toxicity response area was subdivided to allow representation of results for the four test species. Three colors were used to represent degree of concern. The visual representation loses some information in presentation, particularly for chemical results, in not distinguishing between one parameter exceedance and many exceedances.

A numerical sediment quality index was derived from the visual presentation as a further simplification. The index weights each of the three study elements evenly, and converts them to a normalized score with a maximum value of 100. Based on the reference stations, an index above 80 would represent normal or unimpaired conditions.

Summary

Overall summary tables, graphical depictions, or numerical indices all attempt to simplify detailed environmental study results into digestible interpretations. In the final interpretation of sediment quality, monitoring results should be based on the full range of detailed information available that has been derived from the application of several accepted assessment tools. This interpretation should also include an understanding of the study area's history with regard to environmental quality, level of contaminant source control, as well as occurrence of historical remediation efforts and resulting implications on environmental quality.

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APPENDIX 10

TRENTON CHANNEL/DETROIT RIVER SEDIMENT ASSESSMENT AND REMEDIATION

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The Detroit River has experienced over a century of discharges from industry and municipalities. Demonstrable improvements have been made in water quality, loadings, and biota. Common with other International Joint Commission Areas of Concern, sediment of the Detroit River still exhibits organic and heavy metal contamination, toxicity, bioaccumulation potential, and impaired benthic macroinvertebrate communities. Over the past 10 years, considerable attention has been focused on the potential for sediment remediation due to other system improvements. The objective of this presentation is to provide sediment data assessment for the past decade, tools and procedures used to identify and prioritize sediment for potential remediation, and integrated considerations for remedial decision-making and the likelihood of sustainable success.

The Detroit River/Trenton Channel In-Place Pollutants (IPP) Study (Kreis 1988a; 1988b) conducted as part of the Upper Great Lakes Connecting Channels Study (UGLCCS 1988a; 1988b) indicated that sediment of the Trenton Channel was highly degraded using a number of assessment endpoints. Results were consistent with previous studies over the past 20 years which indicated severe sediment impairment in the mainland U.S. nearshore zone from the Rouge River, proceeding south to Lake Erie (MDNR and OMOE 1991). A simple, numerical ranking system was developed for sediment and applied using approximately 300 variables and 9000 measurements as determined during the Trenton Channel IPP Study which included organic and heavy metal analysis, sediment toxicity tests, resident benthos, and other sediment-related parameters (Kreis 1988b; 1989). This system was subsequently expanded by Wildhaber and Schmitt (1996). The measured values of individual variables were subjected to a scaling procedure which allows the relative magnitude of difference among measurements to be retained, results in a compatible scaling for all values, and allows individual variables or combinations of variables to be examined. Weighting procedures were also examined and applied to selected variables when desired. Scaled values were combined by site via averaging (arithmetic mean) individual or combined variables and assigned numerical ranks based on the averages. Numerous iterations which examined different procedures, weighting methods, and statistical evaluations indicated that results were extremely consistent for any method used and were intuitively reasonable based on the raw data. Results indicated that the nearshore area between Monguagon Creek and Elizabeth Park was the most severely degraded in the Trenton Channel. More recent data from the Detroit River (Farara and Burt 1993; Ostaszweski 1997), several prioritization procedure results (Long and Morgan 1990; USEPA 1992; Farara and Burt 1993; MDEQ 1996; Ostaszweski 1997), and comparison to sediment guidelines (USEPA 1977; Persaud *et al.* 1992) indicated consistent findings to the earlier ranking system.

The zonation of degraded sediment quality in the Detroit River is generally known and consistent for the past 20-25 years. All of the prioritization and ranking procedures applied yield the same or similar result. All of the procedures usually include the routinely recommended endpoints including organic and heavy metal concentrations, 3 or more toxicity/bioassay tests, resident benthos, and bioaccumulation assessment. Procedures provide quantitative and relative results which are additionally compared to guidelines/criteria

and hazard is inferred. Although the general historical pattern of degraded conditions was observed, the overall area appears to be larger and includes much of the upper reach of the River, and mercury appears to be a re-emerging issue, based on sediment surveys and other datasets. It has been commonly recommended that sediment sampling should occur approximately once every 5 years to determine changing conditions and this appears to be appropriate.

Sediment remediation has occurred at Monguagon Creek and is proposed for Black Lagoon in the Trenton Channel, among other nearshore sites in the main trunk of the River. Removal of sediment from Monguagon Creek was conducted because degradation of this area has been known for approximately 3 decades, poor conditions had been demonstrated many times using different measures, and the area potentially posed human health hazards (UGLCCS 1988b; Carter and Hites 1992a, 1992b; MDEQ 1996; Conestoga-Rovers & Associates 1996). Removal of sediment occurred from the farthest upstream extent of contamination, downstream to the Detroit River. Because of this and other factors, it appears that this remediation will be long-term and sustainable. Considerations for sediment remediation in the main trunk of the Detroit River, for example the Black Lagoon, are similar to those of Monguagon Creek. The area has been routinely identified as a severely impaired area for approximately the past 15 years, vertical sediment has been examined using coring and acoustical methods, the area is moderately small and well defined, contaminant mass would be removed from the system for protection of downstream areas, and there would be distinct local improvements in environmental conditions (Kreis 1988a, 1988b; UGLCCS 1998a, 1988b; MDNR and OMOE 1991; Farara and Burt 1993; MDEQ 1996; Ostaszweski 1997). Because this area is in the main trunk of the River, upstream inputs and dynamic sediment action has potential to re-contaminate the area, although not to the extent of the present condition. Loadings of contaminants through controls and plant closures have decreased, remained stable, or in limited cases have increased, dependent upon the contaminant examined (UGLCCS 1988b; MDEQ 1996). Historical sediment samples and sediment cores exhibit mixed results as to whether improvements can be observed in sediment concentrations (MDEQ 1996; Ostaszweski 1997). Comparison of sediment-associated parameters of an area dredged for construction purposes after 1 year, to other sites in the Trenton Channel, indicated that contaminant concentrations, resident benthos, and toxicity were not significantly different (Besser *et al.* 1996). Available information suggests that re-contamination would likely occur from inputs and sediment transport, degraded conditions would continue to exist, and the remediation would not be sustainable. Even though major improvements in the Detroit River have occurred, these may not be to the degree necessary to restore beneficial uses. Decisions for sediment remediation would be greatly enhanced by mass balance transport models with predictive capabilities to simulate and forecast the concentrations of sediment which would be deposited at these sites. This tool would allow an assessment of the likelihood that a remediation would be beneficial and sustainable in the main trunk of the Detroit River.

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APPENDIX 11

A FRAMEWORK FOR INTERPRETING NARRATIVE SEDIMENT QUALITY STANDARDS

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Managing contaminated sediment usually requires a balance between environmental and economic considerations. Depending on one's perspective, there are environmental goals in conflict with economic realities, or there are economic goals in conflict with environmental realities. These two viewpoints are really opposing sides of the same coin. Depending on the applicable goals, practices, or regulations, managers can employ many different decision criteria for evaluating site remediation/restoration, source control, or dredged material disposal options. For example, one could maximize the probability of achieving environmental goals, minimize the cost within acceptable risk boundaries, or optimize cost/benefit. Regardless of particular decision criteria, there are three critical elements for effective management of contaminated sediment: risk-based decision-making, weight of evidence assessment, and resource condition monitoring. These elements are dependant on one another (i.e., decisions require assessment, assessment requires monitoring).

The central tenet of a weight of evidence approach is that multiple lines of evidence should support decision-making. The corollary is that no single line of evidence should drive decision-making (unless you believe that a single line of evidence gives you all the information necessary, and you are willing to accept the outcome). A weight of evidence assessment can be implemented in a tiered fashion, with increasingly complex evaluations undertaken only as needed to reduce uncertainty (Ingersoll *et al.* 1997). In a tiered approach, the weight of evidence required should be proportional to the weight (e.g., cost) of the decision.

Contaminants in sediment can cause adverse effects either through direct toxicity to benthic organisms or through bioaccumulation and food chain transfer to human and wildlife consumers of fish and shellfish. Sediment quality assessments are best performed using a weight of evidence approach that incorporate sediment chemistry, laboratory studies of toxicity or bioaccumulation, and field evaluation of the benthic community or fish tissue residues. These lines of evidence can be organized into a sediment quality "triad" that provides the framework for these assessments (Long and Chapman 1985). "Triads" exist for evaluating risk to benthic organisms and risk to human and wildlife consumers.

The problem formulation step of risk assessment involves the *a priori* identification of assessment endpoints (i.e., what is to be protected) and measurement endpoints (i.e., what lines of evidence to evaluate). For a sediment ecological risk assessment, the assessment endpoint may be "a healthy benthic community free from contaminant-induced degradation". Sediment quality triad measurement endpoints are sediment chemistry, sediment toxicity, and benthic community condition. Each of these are associated with uncertainties as they relate to the assessment endpoint. For example, sediment chemistry data do not demonstrate whether measured contaminants are bioavailable. Sediment toxicity tests can indicate bioavailability of contaminants, but test conditions may not reflect field conditions. In addition, the test organisms may not adequately reflect the sensitivity of the full range of species comprising the benthic community. Benthic community condition may reflect degradation from factors other than contaminants (e.g., low dissolved oxygen). Reliance on any one of these measurement endpoints to evaluate exposure and effects is problematic for characterizing risk.

In contrast, a weight of evidence assessment using all three gives the assessor much more information to reach conclusions.

Each presenter at this workshop was asked to describe an assessment approach suitable to support a decision "to act" or "take no further action", with a focus on the scientific tools used in each approach. The answer to the question depends greatly on the action contemplated, and a tiered approach may be most appropriate. However, the "yes/no" aspect to the question is analogous to asking whether or not applicable water quality standards (or objectives) are met. Citizens, responsible parties, and regulated entities expect consistency in the approaches used to assess the condition of protected resources. A good way to achieve this consistency is through State/Provincial adoption of sediment quality standards/objectives and supporting implementation procedures. In the U.S., a water (or sediment) quality standard includes a designated use for the waterbody (i.e., the assessment endpoint) and criteria to meet the designated use (i.e., the measurement endpoints). Criteria can either be numeric ("10 ppm") or narrative ("no toxics in toxic amounts"). Under the U.S. EPA's current policy of independent application, use of numeric criteria conflicts with a weight of evidence approach. However, a narrative criterion can accommodate a weight of evidence approach by design, which can be specified in implementation procedures.

A general model for sediment quality standards for the protection of benthic organisms is the focus of the remainder of this paper. The model is a tiered approach using sediment quality guidelines to evaluate sediment chemistry data as a first step. If guidelines are exceeded, and the weight of the decision requires reducing the uncertainty associated with either contaminant bioavailability or possible effects caused by unmeasured contaminants, standard sediment toxicity tests are used to determine if the standard is met. In this approach, the uncertainty surrounding contaminant bioavailability outweighs the uncertainty in test species sensitivity. This framework is consistent with EPA's current thinking, as stated in EPA's contaminated sediment management strategy: "EPA intends to encourage the States to use biological sediment test methods and sediment quality [guidelines] to interpret the narrative standard of 'no toxics in toxic amounts'" (USEPA 1998).

Sediment chemistry provides information on contaminant concentrations and related chemical variables. Sediment quality guidelines (SQGs) help determine whether contaminants are present in amounts that could cause or contribute to adverse effects. Guidelines based on equilibrium partitioning address bioavailability and can set protective levels for specific contaminants. DiToro *et al.* (1991) describe the technical basis for deriving guidelines using equilibrium partitioning (EqP) theory.

Equilibrium partitioning-based sediment guidelines (ESGs) are based on the theory that an equilibria exists among contaminant concentration in sediment porewater, contaminant attached to a binding phase in sediment (e.g., organic carbon, sulfide), and biota. ESGs are derived by assigning a protective water-only effects concentration to the porewater (such as an FCV), measuring the principle binding phase for a particular contaminant (e.g, fraction of organic carbon for nonionic organics, acid volatile sulfides for metals), and applying a contaminant specific partition coefficient if necessary (e.g., K_{oc}). For nonionic organics, supporting laboratory spiked sediment data show that the predicted sediment toxicity units (based on LC50) agree with percent amphipod mortality within approximately a factor of 2. For metals, spiked sediment are not toxic to amphipods if the molar concentration of simultaneously extracted metals (SEM) does not exceed the molar concentration of acid volatile sulfides (AVS).

Contaminants almost always occur as mixtures in sediment. Guidelines for chemical mixtures are most useful for contaminants that tend to co-occur, have the some toxic mode of action, and have the same factors control bioavailability. Field data from sites thought to be exclusively contaminated with mixtures of PAHs (Swartz *et al.* 1995) effectively illustrate what sediment chemistry data can tell you and what it cannot tell you. Although sediment quality guidelines bound the range of tested amphipod mortality (i.e., provide a good screen), the range of concentrations where toxicity may or may not occur exceeds an order of magnitude. It is within this range that sediment toxicity tests can help determine whether effects are occurring and if standards are met.

Sediment toxicity tests provide a direct measure of effects, account for bioavailability, and can be standardized for multi-region use. On the other hand, they may not adequately represent all species that a standard intends to protect, they cannot differentiate among contaminant or natural geochemical causes of toxicity, and

they may not represent field conditions (e.g., sediment collection, handling, storage, and manipulation may alter the natural bioavailability). *In situ* application of toxicity tests can help mitigate the latter limitation.

Several EPA and ASTM standard methods are available. EPA methods include short-term and long-term exposure tests for survival, growth, and reproduction of freshwater midge larvae and freshwater and marine amphipods. Use of standard methods increases data accuracy and precision, facilitates test replication, increases the comparative value of test results, and ultimately, increases the efficiency of regulatory processes requiring sediment tests.

The full sediment quality triad includes assessment of the benthic community condition. The methods available are many and varied, ranging from simple presence of indicator organisms, to areal abundance of species, to complex multi-metric statistical indices. Some of these methods are currently in use in various State water programs (e.g., Ohio), and could be specified in narrative standard implementation procedures as an additional tier. However, benthic community assessment is not a predictive tool: the effects have already been manifested. Elevated levels of contaminants in sediment, along with demonstrated laboratory or *in situ* toxicity, may be sufficient to "take action" to prevent degradation even in cases where a benthic community assessment does not indicate impairment.

Available field data indicate that sediment toxicity tests are predictive of benthic community impairment. A recent analysis of regional sampling data indicated that reduced amphipod survival is predictive of benthic community degradation approximately 75 percent of the time (Scott 1998). An example of this relationship using samples taken from Baltimore Harbor (McGee *et al.* in review) shows that a line drawn at 70 percent test survival effectively divides amphipod abundance into distinct groupings: samples with fewer than 100 organisms per square meter and samples with greater than 100 organisms per square meter. However, other field data sets suggest that survival alone may not be sufficiently protective or predictive of field conditions. Samples from coastal Southern California indicate that moderate degradation, as measured by amphipod abundance and species richness, occurs co-incident with moderate chemical contamination, yet without associated reduction in amphipod survival from laboratory toxicity tests (Swartz *et al.* 1986). The implication that sub-lethal effects may be responsible for field population effects is supported by laboratory data measuring multiple test endpoints. Using dose-response curves for amphipod survival, growth, and reproduction, moderate levels of contamination (i.e., 10% of a highly toxic sediment), there is no reduction in survival; yet reduction by half in growth rate and by a factor of 4 in reproduction as measured by offspring per female (DeWitt *et al.* 1997).

Considering the above information, an example implementation procedure for a narrative sediment quality sediment is provided. This freshwater example makes use of protective ESGs and predictive standardized toxicity tests using a lethal and sub-lethal endpoint for two representative species. Key elements of a successful sediment management program include frequent monitoring of resource conditions; field evaluation of sediment chemistry, biological tests, and benthic community; harmonization of affected regulatory programs; and agreement among stakeholders and scientific peer review. One of these key elements, harmonization of affected regulatory programs, is illustrated by the sediment management approach in Washington State. In Washington State, source control, dredged material disposal, and contaminated sediment cleanup programs all share the same sediment quality standards. These standards are implemented using sediment quality guidelines and sediment toxicity tests, and this Washington program serves as the model for the framework proposed in this paper (Ecology 1995).

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APPENDIX 12

ECOLOGICAL RISK ASSESSMENT FOR THE CONTAMINATED HARBOR SEDIMENT ADJACENT TO THE ASHLAND, WISCONSIN LAKEFRONT PROPERTY - KREHER PARK

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Introduction

The Wisconsin Department of Natural Resources (WDNR) through Short Elliott Hendrickson Inc. (SEH) recently completed an Ecological Risk Assessment (ERA) for the contaminated sediment in an area that comprised approximately 4.05 hectares of the harbor that extends from 92 to 213 m off shore from Kreher Park in water less than 3.05 m deep and between jetties to the east and west. Previous investigations have identified the contaminants of concern as volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbon compounds (PAHs). The contaminants are associated with black tarry materials and appear to be most concentrated at the interface of a wood chip layer (that covers a large part of the area to an average depth of 22.5 cm) and the underlying fine sands and silty sands. The contamination was generally present in the upper 3.05 m of the sandy sediment and decreased with depth till underlying, cohesive parent materials were reached.

Contaminants sources

Given the large area of bottom sediment contaminated and the visible black, tarry characteristics associated with the contamination, there is only a limited number of possible contributing sources to this type of contamination. A major contributing source was likely releases of coal tar wastes from the Manufactured Gas Plant (MGP) that operated up on the bluff from the late 1800s until 1947. MGPs generated gas for residential heating and lighting from heating coal in retorts. Coal tars were a by-product of the gas generation process. Disposal of waste products were largely unregulated during the period of active coal gas production. Coal tars from the Ashland MGP have been identified in the ravine off of the bluff, the deep groundwater aquifer, and in the filled area of the Ashland Lakefront property.

As more and more MGP sites are being investigated around the state, coal tar wastes are being found in the bottom sediment of surface waters associated with a large number of the sites. Even 40-50 years after the MGPs have ceased operating, the coal tar wastes have remained at or near the sediment surface and at a depth to impact aquatic resources on a continuing and long-term basis. Organic and metal compounds from MGP wastes are toxic to bottom-dwelling organisms and can be released from bottom sediment by various means to the overlying water in dissolved forms, associated with suspended particulates, or as separate oils, all of which may be available and toxic to fish and other aquatic organisms. Coal tar wastes may contain thousands of organic compounds of which there is the ability to routinely analyze and identify only a portion. Many of the unidentified may be as equally toxic as those that can be identified.

Ecological risk assessment

The purpose of the ERA was to estimate the current and future risks and impacts from contaminants of concern present in the surface waters and sediment of the site to plants, fish, and other aquatic organisms that would normally occupy the site habitats and birds and wildlife that may use the habitats as part of their foraging base. A previous assessment looked at the risks to human health from exposure to the site contaminants.

The ERA used a weight of evidence approach to link the observed and measured sediment and water contamination found at the site to actual and predicted impacts to fish and other aquatic organisms that may use the harbor area off of the Lakefront property. The weight of evidence approach depends on using multiple methods of associating the contaminants levels to effects to different organisms who are exposed to the contaminants by different exposure routes.

The weight of evidence of impacts was built on the following:

- Representative fish, water column, and benthic test organisms were exposed to sediment, and water was collected from the contaminated site and a clean site in a series of laboratory toxicity tests.
- Samples of the organisms inhabiting the bottom substrates of the site were collected to look at the number and diversity of species present and compared with those from uncontaminated sites.
- Review of the results of studies conducted on other sites with the same groups and levels of the contaminants of concern and methods of exposure to organisms occurred.
- The use of published guidelines or criteria that relate sediment and water concentrations of the contaminants to effects on fish and other aquatic organisms, and a comparison of these guideline/criteria concentrations to measured concentrations found at the site occurred.

Integration of the above study components leads the WDNR to conclude that the ecological risks associated with the contaminated sediment off of the Ashland Lakefront property are likely to be high for the present and for the long-term. Given the bottom characteristics, PAHs will not attenuate or naturally beak down over time as evidenced by their toxicity 50-60 years after being released to the harbor. Risks and impacts to the insects, worms, crustacea, and other species that inhabit the bottom substrates for all or some portion of their life cycles and for water column organisms such as immature fish, are expected to be highest. The bottom-dwelling community serves as part of the food chain that supports higher trophic levels or larger consumers such as fish. It is likely the bottom dwelling community is limited as a food source at the site, and those organisms that can survive may accumulate PAH contaminants and pass them onto higher level consumers. Immature fish impacted by the site contaminants also means a possible loss of a food base for higher level consumers and loss of fish stock to the bay and the lake. The health of larger fish utilizing the area may also be impaired.

Some of the PAH contaminants at the site have the unique characteristic of having their toxicity to bottom-dwelling and water column organisms such as fish enhanced or increased by sunlight that can penetrate through the water to the bottom substrates and activates the PAHs in the process (Table 1). In all the above cases, the direct evidence indicates that the shallow nearshore habitat off the Ashland Lakefront property is impaired and not supporting a healthy, balanced community of aquatic organisms. These impacts may have secondary impacts to higher trophic level organisms such as birds and wildlife that use the habitat as a foraging base.

Feasibility study for sediment remediation

Based on the results of the ERA, the WDNR will be undertaking a feasibility study to evaluate remedial alternatives for the contaminated sediment of the site. The overall objective for remediating the contaminated sediment off of the Lakefront property is to protect the unique resources of the Chequamegon Bay and Lake Superior Ecosystems. All necessary means will be taken to protect these resources from any degree of degradation or impairment.

Summary of ecological risk assessment - weight of evidence

Benthic Community:

- Adsorbed chemical PAH and VOC concentrations in sediment
- Exceedance of several different sediment effects benchmarks for PAHs and VOCs concentrations in sediment
- Impacted benthic community per Spring 1998 survey
- Toxicity study results indicate PAH contaminated sediment is toxic to benthic organisms
- UV exposure results indicate PAH contaminated sediment is toxic to benthic organisms
- Degradation of lower order food chain microorganism populations based on microbial enumeration bioassays

Aquatic Community:

- Adsorbed chemical PAH and VOC concentrations in sediment
- Exceedance of several different sediment effects benchmarks for PAHs and VOCs concentrations in sediment
- PAH concentrations in sediment at levels comparable to those associated with tumors in fish at other sites
- Exceedance of accute and chronic criteria for water quality during wave action
- Reports of sheen and odors in surface waters above contaminated sediment
- Potential for release of more heavily contaminated deeper sediment due to natural or anthropogenic disturbances
- Toxicity study results indicate PAH contaminated sediment is toxic to fish fry
- UV exposure results indicate PAH contaminated sediment is toxic to fish fry and *daphnia magna*

Terrestial Community:

- HHRA indicated risk of cancer to humans from exposure to sediment or contaminated water
- Lower order food chain impacted - decreases quantity and quality of fish and other food sources
- Potential for uptake of PAH contaminants by terrestial organisms feeding on lower order aquatic or benthic organisms that may bioaccumulated contaminants

Identification

Site identification:

- Planning on a Watershed basis
- Assessment on a Watershed basis
- Other sediment remediation projects
- Fish consumption advisory monitoring
- Wildlife monitoring programs
- Other

Ashland Harbor site identification:

- Known coal gasification site
- Other coal gasification sites with serious problems
- Expansion of local Wastewater Treatment Facility

Tiered approach

- Comparison of contaminant concentrations with reference/background sites
- Comparison with existing effect-based sediment guidelines
- Simple partitioning models for non-polar organic compounds
- Site specific studies that integrate sediment chemistry, laboratory toxicity/bioaccumulation, and field studies
- Fate and transport modeling
- Human health and ecological risk assessments

Field collections at Ashland Harbor site

Sediment chemistries:

- 80 locations @ 30.5 m grid spacing
- Sediment depths to 7.5 m
- PAHs, VOCs and others

Surface water samples:

- High wind and wave periods

Biological studies:

- Benthic macroinvertebrates - 4 habitat types and tissue PAH concentrations
- Fish studies - tissue PAH concentrations and fish health assessment

Ashland Harbor sediment toxicity testing

4 Sample sites:

- Reference wood and sand
- Contaminated wood and sand
- Results expressed in Toxic Units

Solid phase tests:

- *Hyalella azteca*
- *Chironomus tentans*
- *Lumbriculus variegatus*

Sediment Elutriate tests:

- *Daphnia magna* (48 Hr)
- *Pimephales promelas* (7 day)

Photo-enhanced Toxicity tests:

- *Lumbriculus variegatus*
- *Daphnia magna*
- *Pimephales promelas*
- 2-4 hours Ultraviolet exposure
- Results expressed in Toxic Units

Table 1. PAH sediment concentrations and related toxicity units at the study sites

Type of Bottom Substrate Sampled	Total PAHs mg/kg (dry wt.)	Sum of UV Toxic PAHs[1] Organic Carbon Normalized mg PAH/kg TOC	Total Toxic Units[2]	
			Based on dry wt.	Organic Carbon Normalized
Reference sand	.424	40.9	1	7
Contaminated sand	.145	15	7	119
Reference wood	6.543	41.1	31	14
Contaminated wood	370.2	8,294	1,711	3,728

1. PAHs identified to be associated with phototoxic effects based on the literature - anthracene, benzo(a)pyrene, dibenzo(a)anthracene, pyrene, benzo(k)fluoranthene, and benzo(g,h,i)perylene.

2. Based on Ingersoll HA 28 d ERM values or Effect Range - Median values. ERM values associated with frequent or probable adverse biological effects.

Sediment concentration of the PAH compound/HA 28 d ERM concentration for the PAH compound = Toxic Units.

Toxic Units for individual PAHs at a site are summed to derive a Total Toxic Unit value for the sample site.

APPENDIX 13

THE SED-TOX INDEX FOR THE ASSESSMENT AND RANKING OF SEDIMENT HAZARD POTENTIAL: HOW IS IT USEFUL FOR DECISION-MAKING?

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Summary

Toxicity evaluation under controlled laboratory conditions is an important component of sediment risk assessment. It is commonly accepted that a single species can never adequately reflect contaminant effects to all biota in the aquatic ecosystem under study. This calls for the use of several test species representing different trophic levels in the test battery. Micro-scale toxicity tests have shown good correlation with macroinvertebrate assays, benthic organism responses, and contaminant levels. These tests are proving to be attractive to the scientific community at large because of their cost-effectiveness in providing rapid and reliable results. However, the use of a testing battery requires a tool to integrate multiple toxicity data in a ranking process that allows the managers to determine the extent of the problem, identify hot spots and assess the need to "act" or "take no further action" on a particular site. The goals of this paper are to introduce the Sediment Toxicity (SED-TOX) Index for the assessment and ranking of toxic hazards in sediment, illustrate its application with results from a battery of bioassays performed on four exposure phases (pore water, wet sediment, organic extract, and whole sediment), and compare the SED-TOX scores with benthic community metrics. The discussion will emphasize on how the Index can be used to make sediment management decisions.

Introduction

Contaminated sediment samples may contain complex mixtures of contaminants. In such cases, it is widely accepted that one cannot rely on a single bioassay to detect all potential hazards (Cairns 1986; 1988). If the purpose of toxicity testing is to protect the environment from the action of toxicants, the testing program must optimize its ability to detect contamination. Batteries of tests are now commonly used for that purpose. The assessment of toxicity in multiple bioassays provide data that may be used to assess integrated responses at several levels of organization simultaneously. A battery of tests typically covers several trophic levels and several effect endpoints (e.g., enzymatic activity, genotoxicity, growth, reproduction, survival). The battery approach for the assessment of contaminated sediment has been recommended by several organizations such as Environment Canada, the US. EPA, and the International Joint Commission.

Test batteries may, however, generate contradictory results in the data set, which may lead to difficulties in the decision-making process related to the management of contaminated sediment. This complexity calls for a mathematical tool to integrate toxicity data and provide comparable indices for comparing test sites with reference sites, identifying hot spots, determining spatial gradients to identify contamination source, monitoring following remedial actions, and establishing criteria. Between 1994 and 1998, efforts have been devoted at the St. Lawrence Center to develop an index which could integrate multiple endpoint measures into a

single value. The resulting SED-TOX Index evaluates and compares the relative hazard associated with contaminated sediment from different sites based on a suite of toxicity tests (Bombardier and Bermingham 1999). Following its development, we have expanded upon the SED-TOX approach in efforts to develop a basis for evaluating benthic impacts in relation to multiple measures of toxic responses. This presentation will describe the SED-TOX Index, provide an example for its application, and show how SED-TOX scores can be used to predict benthos degradation.

Some Terminology

Hazard: Likelihood of adverse toxic effects occurring as a result of exposure to one or more contaminants at a particular site.

Battery approach: The use of a variety of species representative of different trophic levels and sensitivity to toxicants to evaluate the toxic potential of contaminant mixtures, considering several exposure routes. It is believed that using several test organisms and exposure phases increases the probability of correctly identifying sediment that would be expected to be toxic to aquatic organisms under field conditions.

Exposure phase: The matrix used in the sediment toxicity tests (e.g., pore water, elutriate, unmodified whole sediment). Tests on pore water, which typically contains free salts, solutes, colloidal material, and/or organic solutes, provided information on the toxicity of dissolved substances in the aqueous phase. Wet sediment phase tests yielded information on the potential toxic effects of contaminants sorbed to sediment particles that could be released in the water column during disposal of dredged material or during resuspension events. Whole sediment bioassays measured the effect of all bioavailable contaminants, where bioavailable is defined as the fraction of the total contamination in the interstitial water and sediment particles that is available to aquatic organisms. Finally, exposing organisms to organic extracts constituted a worst-case scenario since extracting sediment with a solvent such as methylene chloride releases toxic molecules which become much more bioavailable in toxicity testing. "Worst-case" implies that the effects demonstrated with sediment organic extracts may never be demonstrated in the field, but if they are, this type of testing can be considered proactive.

Recommendation of an appropriate testing strategy for the assessment of sediment - Environment Canada (Quebec Region)

In 1995, a joint venture partnership was struck between BEAK International and Environment Canada (St. Lawrence Centre, Eco-Innovation Technologique) to conduct a comprehensive study to assess the suitability of various microscale tests for sediment toxicity assessment, and to recommend an appropriate battery for freshwater sediment. The performance of microscale tests was appraised by comparing their responses with those of macroinvertebrate assays, benthic community structure indices, and sediment contaminant characteristics (Côté *et al.* 1998a; 1998b). Twenty different toxicity test methods were performed on 15 sediment samples and evaluated for their inclusion in the testing strategy:

Pore water (a):
Bacteria:
Microtox acute test
Mutatox
SOS Chromotest
Microtox microplate
Microtox chronic test
Algae:
Chronic test
Acute test
Microinvertebrates:
Thamnotoxkit
Rotoxkit
Daphtoxkit
Algaltoxkit
Hydra

Pore water (b):
Biomarkers:
Hepatocytes (viability, MFO, MT, DNA damage)

Wet/Whole sediment (c):
Bacteria:
Microtox solid phase test
ToxiChromoPad
Algae:
Direct contact test
Macroinvertebrates:
C. riparius (survival, growth)
H. azteca (survival, growth)

Organic extract (d):
Bacteria:
Microtox acute test
Mutatox
SOS Chromotest
Microtox microplate
Mictotox chronic test
Microinvertebrates:
Thamnotoxkit
Daphnia IQ
Hydra

n = 21 biotests

After assigning hazard categories for each bioassay, response agreement of microscale bioassays was gauged against macroinvertebrate bioassays, contaminant levels, and measures of benthos degradation. Tests which showed good concordance with chemistry, macroinvertebrate test results, and benthic community data were retained for their inclusion in the battery approach, along with two conventional bioassays:

Trophic level	Assay	Exposure phase
Primary producers	*Selenastrum capricornutum* (Direct contact test)	Wet sediment
Primary consumers	*Hyalella azteca, Chironomus riparius* (survival)	Whole sediment
	Thamnotoxkit™, Daphtoxkit™	Pore water
Secondary consumers	*Hydra attenuata* (tentacles morphology)	Pore water
Decomposers	Microtox - *Vibrio fischeri*	Pore water
	SOS Chromotest (genotoxicity) *Escherichia coli* PQ37	Pore water

SED-TOX calculation

Once toxicity has been assessed through the use of such a battery, data can be integrated in the SED-TOX formula as follows:

1. Data are assembled in the SED-TOX spreadsheet (Excel™)
2. Data are converted in TU adjusted for sediment dry weight
3. Mean toxic scores are derived for each exposure phase (WAPT scores - or weighed average phase toxicity)
4. Bioassays are weighed according to sensitivity
5. WAPT scores are cumulated, and divided by the total number of exposure phases considered in the battery (r), resulting in the CAPT (cumulated average of phase toxicity) score
6. CAPT scores are multiplied by the number of exposure phases that elicited toxicity, and then log transformed to result in the SED-TOX score

The formula for the Index calculation is as follows: $\text{SED-TOX} = \log10[1+n(\text{CAPT})]$

where: n = number of phases eliciting toxicity

CAPT = cumulative average of phase toxicity

and n(CAPT) is the Toxic Print

A spreadsheet program has been developed by the St. Lawrence Centre to perform those calculations automatically. This program is available for free.

Cutpoints separating four toxic hazard levels were defined. SED-TOX scores may vary from 0 to 4. A SED-TOX score of 0 indicates no toxic hazard potential; for values between 0.1 and 1, the toxic hazard is considered marginally toxic; for values between 1.1 and 2.0, toxic hazard is considered moderately toxic; and scores greater than 2 are considered highly hazardous.

Application

The Index was applied to data collected from 2 marine sectors in the Gulf of St. Lawrence. Three sites were assessed within each sector (a site considered for dredging and suspected for presenting high levels of contaminants, a site considered for disposal of the dredged material, and a reference site located nearby). Results clearly indicated that the SED-TOX Index discriminated the hazard potential of the dredging sites (some stations showing high scores), as compared to their respective reference sites (mostly marginal scores). SED-TOX scores were then compared to chemical concentrations. Sites with the highest levels of contaminants had the greatest ratio of high SED-TOX scores, while those with toxicant levels below the sediment quality criteria had the highest ratio of marginal SED-TOX scores. However, the relationship was not linear.

Comparison with benthic community metrics

We also wanted to verify if the SED-TOX Index could be used to predict adverse effects on the benthic community (measured via benthic community responses in field samples). Data on benthos degradation were derived from 15 sediment samples taken from different areas in the St. Lawrence River. The battery of bioassays put forward by BEAK International and EC (see table shown above) was used to assess sediment toxic potential. Benthic community data were used to calculate a variety of metrics, including the total number of taxa, the Shannon-Wiener Index, taxa richness, and number of intolerant or tolerant species. All graphs showed a consistent pattern: degraded benthos was associated with high SED-TOX scores (i.e., > 2.0). Indeed, total number of taxa, the Shannon-Wiener Index, and taxa richness all decreased with increasing SED-TOX scores. Oligochaetes (tubificids) accounted for 75% of the benthic species in sites that showed high SED-TOX scores, as compared to 20% in sites with moderate toxicity scores. The relative abundance of sensitive species (e.g., caddisflies) was greater at sites with lower SED-TOX scores. These preliminary results suggest that the cutpoint of 2 for identifying highly toxic sediment may be useful at predicting degraded benthos. This toxic hazard threshold, however, remains to be validated with a greater number of sediment samples.

Concluding remarks

The advantages of the Index:

- Is founded on generally accepted concepts and principles
- Allows the incorporation of an unlimited number of toxicity tests; however, the use of redundant information may overload the Index and reduce its discriminatory power
- Considers all possible exposure routes for aquatic organisms
- Takes into account the relative sensitivity of the exposure phases and that of the effect endpoints
- Can be used on data already gathered – no age limit for data set

The disadvantages of the Index:

- Requires professional judgement to interpret SED-TOX scores
- Time of sample collection and composition of the test battery should ideally be the same
- Does not take into account the variability of the tests, therefore requires the use of standardized methods

Post-hoc evaluation of the Index - refinement of the Index should focus on the:

- Influence of inconsistency of test selection and temporal scale of sampling on Index scores
- Validation of the range of SED-TOX scores and threshold levels with field data
- Inclusion of sediment volume in the formula, so as to compare not only Toxic Prints but also Toxic Loads

Possible applications of the Index:

- Assess the need "to act" or "take no further action"
- Determine the spatial gradient of toxic hazard
- Establish priorities - identify hot spots
- Evaluate the progress of remediation
- Define the composition of a test battery - identify redundant tests to reduce the analytical effort at subsequent sites

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APPENDIX 14

CONTAMINATED SEDIMENT: WHEN IS CLEANUP REQUIRED? THE WASHINGTON STATE APPROACH

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Introduction

Washington State was the first jurisdiction in North America to adopt sediment quality criteria, including narrative standards, numeric biological effects criteria, and numeric chemical criteria. In addition, a decision framework was developed to use these criteria in deciding when to list a contaminated site, when cleanup is required, when source control is required to protect sediment, and when dredged material is unsuitable for open-water disposal. Unlike most other sediment quality criteria currently used in State and Provincial programs, these criteria are not used as screening levels, but as actual cleanup standards.

While the numeric standards originally only applied to benthic toxicity in marine sediment, the Department of Ecology (Ecology) is currently engaged in development of freshwater criteria and human health criteria, which will be incorporated into the next round of rule revisions (late 1999-early 2000). Although these numeric criteria have not yet been finalized, the decision framework is the same as for marine sediment, and is equally applicable to all environments. This framework is described below, and can be used with or without promulgated numeric criteria.

Protected endpoints

It is important to recognize that contaminated sediment has three potential pathways of concern, each of which must be considered in conducting a site investigation and selecting cleanup standards:

- Benthic toxicity
- Bioaccumulative risks to fish and wildlife
- Human health

Existing sediment quality guidelines and interpretive frameworks (e.g., sediment quality triad) often address only benthic toxicity, whereas risk assessment approaches often focus on food web models and bioaccumulation issues. Any complete method for determining when a contaminated site requires cleanup must include consideration of all three pathways and tools that address these pathways. These three end-points should not be played off against each other in a preponderance of evidence approach - each is a protected endpoint in and of itself, and exceedance of any one guideline should trigger action.

Tiered decision framework

A tiered approach to decision-making is the heart of the Washington State approach to determining when a site requires cleanup. In theory, for each pathway there would be three types of criteria:

- A narrative standard that provides a conceptual statement of a level above which cleanup is required - for example, "no more than minor acute or chronic adverse effects to the benthic community"
- An effects-based (or biological) standard that is, in effect, a translation of the narrative standard into specific measurable terms - for example, "no more than 30% mortality in the *Hyalella azteca* acute 10-day bioassay"
- A numeric chemical criterion corresponding to the narrative and biological effects levels

The bullets above are listed in order of development; that is, an agency normally develops the narrative standard first, then translates that narrative standard into more specific effects-based criteria that can be measured in the field. Third, once enough chemical and biological data have been collected, a numeric criterion can be calculated that corresponds to the effects-based and narrative standards. For any given pathway, the agency may be in different stages of criteria development. If the more specific numeric standards have not yet been calculated, either the effects-based criteria or the narrative standards can be used to guide site-specific approaches to cleanup determinations.

At any given site, a three-tiered approach can be used, described below. Lower tiers cost less in terms of time and resources, but may be less accurate in terms of site-specific effects than higher tiers. Any of the tiers can be used to make cleanup decisions. The decision to proceed to a higher tier may be made by either the responsible party or the agency.

Tier 1 - Numeric chemical criteria. Once the numeric criteria are calculated, they can be used as a "short-cut" at smaller or less controversial sites, to save money, time, and resources. If the responsible party and the agency agree, the chemical criteria can be used directly to delineate site boundaries and set cleanup standards. For this approach to work well, the chemical criteria must be relatively accurate in predicting biological effects, rather than weighted toward the conservative side (e.g., Ontario screening levels). In other words, equal consideration must be given to false positives and false negatives, and chemical criteria calculated that have a high overall accuracy rate in predicting actual effects in the field. This is one reason that Apparent Effects Thresholds (AETs) appear less conservative when compared to approaches such as TELs/PELs, because they are designed to be used as actual cleanup standards, not as screening levels.

Tier 2 - Effects-based criteria. At any site, either the responsible party or the agency can request to conduct field measurements of biological effects in lieu of using chemical criteria. The results of these tests are then compared against the numeric effects-based criteria as in the second bullet above. These results always override the chemical criteria, because they are considered more direct measurements of adverse effects. This is true regardless of whether the chemical criteria were passed or failed.

Tier 3 - Site-specific risk assessment. If there are no effects-based criteria yet developed that are representative of the types of pathways or effects seen at the site, then the narrative standards are used to guide a site-specific ecological or human health risk assessment that addresses that specific pathway of concern.

The following sections describe the specific approach to making cleanup decisions for benthic effects and bioaccumulative risks used in Washington, under each of the three tiers.

Benthic effects

Tiers 1 and 2 are available for benthic effects in marine sediment - both numeric chemical and biological standards exist. Tier 3, site-specific risk assessment, is seldom or never used for benthic effects because adverse effects can be directly measured and compared against the numeric criteria; there is no need for modeling or probabilistic approaches.

Under Tier 1, AETs are used as chemical criteria. At least 4 AETs are calculated for each chemical, each of which represents a different species or biological test. AETs currently promulgated include the amphipod *Rhepoxynius abronius* acute bioassay, oyster larvae survival and abnormal development test, Microtox, and benthic effects. AETs have also been recently calculated for the echinoderm *Dendraster excentricus* larval bioassay, and the *Neanthes arenaceodentata* growth test. The lowest of the AETs is used as the long-term goal for sediment quality in the State, and the second-lowest AET is used as an upper limit for cleanup. A site-specific cleanup level is selected as close as possible to the long-term goal, but no higher than the second-lowest AET. This gives site managers some flexibility to address site-specific conditions of cost, feasibility, and net environmental benefit.

As an alternative to using chemical standards, Tier 2 biological effects levels may be used. Under Tier 2, a responsible party must conduct a suite of 2 acute and 1 chronic biological tests from an approved list of bioassays and benthic community studies, and compares the results of these tests to the promulgated biological criteria. For each approved test, Ecology has defined two levels of impact. The lower level of impacts typically corresponds to the minimum detectable difference in comparison to a reference station. A higher level of impact might be 30-50% adverse effects such as mortality, reduction in growth, or abnormal development. The results of the bioassays are scored against these levels of impact for each station tested. If two tests show a low-level impact, or one test shows a high-level impact, then that station is considered to exceed the cleanup level. All the stations showing impacts are mapped, and a cleanup boundary selected that includes the impacted stations.

For freshwater sites, numeric chemical and biological effects standards are not yet promulgated. Draft biological effects standards for two freshwater bioassays have been developed and included in the Dredged Material Evaluation Framework for the Lower Columbia River Management Area. Ecology's regulatory workgroup is considering these and additional biological standards for inclusion in the next round of rule revisions. The draft biological criteria are presented below. In the mean-time, site managers are selecting appropriate freshwater bioassays and determining site-specific biological effects criteria for comparison to field data, using criteria and decision frameworks analogous to the marine criteria.

Bioassay	Low-Level Effect	High-Level Effect
Amphipod *Hyalella azteca* (10-day mortality test)	Mortality greater than reference station[a]	Mortality 15% higher than reference mortality
Midge *Chironomus tentans* (10-day mortality test and 10-day growth test)	Mortality greater than reference station[a] and Biomass less than reference station	Mortality 20% higher than reference mortality and Biomass 60% of reference biomass[a]

a. Difference must be statistically significant (alpha = 0.05).

Draft freshwater AETs have also been calculated for *Hyalella azteca* and Microtox, but there are not yet enough data to calculate AETs for other tests. Because at least 4 AETs are needed to promulgate numeric chemical cleanup standards, more data will be needed before chemical criteria can be published.

Bioaccumulative effects

Bioaccumulative effects are of concern for both people and fish/wildlife. Because these criteria are calculated in essentially the same way, both are treated together here. All three tiers are under development for the next round of rule revision in Washington. Tier 1 would consist of specific sediment quality criteria that were developed using bioaccumulation models back-calculated to sediment. These are derived in the following manner:

- Acceptable risk levels are selected (e.g., 1x10-6 risk for carcinogenic effects in humans)
- Exposure scenarios are developed, including consumption rates, exposure frequencies, etc.
- These input values are used in standard EPA equations to back-calculate acceptable concentrations in fish, termed Target Tissue Levels (TTLs)
- For wildlife, TTLs may also be selected based on tissue residue-effects databases or food-web models
- TTLs are back-calculated to sediment quality criteria using Biota-Sediment Accumulation Factors (BSAFs)

Draft Tier 1 sediment quality criteria have been developed by Ecology and are under consideration for promulgation in the next round of rule revision. Similar to benthic effects criteria, a range of acceptable sediment quality levels will probably be derived (for example, based on a range of 1x10-6 to 1x10-5 carcinogenic risks in humans) that would give site managers some flexibility in selecting cleanup standards at a site.

Because there is currently still a great deal of uncertainty in the BSAF portion of the model, Tier 2 will likely consist of using the TTLs directly as effects-based criteria. A responsible party could collect fish and shellfish from the site, or conduct laboratory or *in situ* bioaccumulation tests, and compare the measured tissue levels with the TTLs directly. If the TTLs are exceeded, the results of these tests could also be used along with surface sediment data to derive a site-specific BSAF, which could then be used to back-calculate site-specific sediment quality criteria.

Tier 3 would consist of site-specific food web modeling for ecological risks, or use of site-specific human health exposure scenarios, if unusual receptors or exposure pathways existed at the site.

Summary

In summary, in Washington State, cleanup decisions are made on the basis of both benthic toxicity and bioaccumulation pathways. For each pathway, several tiers are available for determining whether the level of risk warrants cleanup, ranging from numeric sediment cleanup criteria, to biological effects-based criteria, to site-specific risk assessments. The results of higher tiers, being more resource-intensive and more site-specific, always override the results of lower tiers. The decision to proceed to a higher tier may be made by either the responsible party or the agency, and may depend on the size and complexity of the site, the potential for unusual bioavailability or exposure issues, and the resources at risk at the site. Higher tiers are always used if chemicals or exposure pathways are present that are not represented by the numeric chemical or biological criteria available for lower tiers.

APPENDIX 15

APPLICATION OF COMPUTER MODELING AND BIOMONITORING IN DECISION MAKING FOR THE ST. CLAIR RIVER AREA OF CONCERN

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Introduction

The International Joint Commission has identified the St. Clair River as an Area of Concern within the Great Lakes Basin. Based on recent and historical data collected by the Ontario Ministry of the Environment, Environment Canada, and the Industrial sector (including the Lambton Industrial Society), a study area of approximately 75,000 m^2 (7.3 hectares) was selected for more intensive study and analysis. This area, referred to as the Study Area #1, is located on the Canadian side of the St. Clair River just south of the City of Sarnia.

The contaminants in Study Area #1 are primarily due to historical point source loads, all of which have been significantly reduced in the past 10 years, although a detectable load of HCB still enters the River through the Cole Drain. Loads used in this report reflect measurements taken in 1995 as reported by Kauss (1996). Remedial measures undertaken by Dow Chemical Canada Inc. in 1997 are expected to reduce the loads emitted via the Cole Drain to the St. Clair River. In anticipation of these load reductions, this report evaluates the impact of Cole Drain at 1995 and projected 1997 (no load) levels. However, persistent toxic substances (including HCB and mercury) that have already accumulated in bottom sediment pose a hazard to the aquatic environment and its users (Persaud *et al.* 1993) and may, in part, be responsible for 5 out of 9 of the St. Clair River use impairments as defined by the Great Lakes Water Quality Agreement (MOEE 1995). In addition, the contaminated sediment creates a risk of being transported (over time or by accidental release) to the downstream lakes, where as dispersed contaminants, it will be virtually impossible to clean up (IJC 1997).

Component studies

To assist in the decision-making process in the St. Clair River Area of Concern, six complementary studies were undertaken:

- Biomonitoring/biotoxicity analyses;
- Resolution of spatial extent of sediment contamination;
- Sediment resuspension and deposition studies;
- 3-D hydrodynamic and mass transport model;
- WASP5/IPX in-place pollutant fate and transport model; and
- Construction of GIS for the St. Clair River Area of Concern.

Summary of findings

The following is a summary of the findings of this study:

- Cytotoxicity and enzyme induction studies showed that the sediment in the Study Area #1 could be hazardous to benthic organisms;
- The total area of contaminated sediment under study, of 75,000 m^2 (approximately 7.3 hectares), was estimated to contain 400 kg of HCB and likely similar quantities of other chemicals including Hg and HCBD;
- Based on a triad-like, weighted, numerical score including chemistry, biodiversity, and acute and chronic toxicity (i.e., the Total Sediment Quality Score or TSQS), 20% or 4,500 m^3 of the total volume of sediment (approximately 23,000 m^3) in the Study Area #1 is highly contaminated and requires remediation;
- Up to 40% of the 4,500 m^3 of the highly contaminated sediment could be gravel or other hard substrate that would not require treatment;
- Ship effects account for a significant amount of resuspension of fine sediment;
- The water column concentrations of HCB at the Study Area #1, as inferred from the clam tissue analysis, was less than 2-3 ng/L, which is consistent with the IPX model's predictions and field measurements;
- The estimated HCB export from the Study Area #1 for present conditions is 15 g/d;
- If the do-nothing option is taken, there will be a 25% decrease in this flux of HCB by the year 2010;
- The half-life of contaminants in the Study Area #1 is approximately 20 years;
- Implementation of capping or dredging of the 4,500 m^3 of most contaminated sediment (respective area of approximately 1.6 hectares) would reduce the flux of HCB from the site by 90% by the year 2010;
- Environmental dredging will introduce a short-term increase in the flux of chemicals from the site; based on the analysis of the 1995 environmental dredging at this site, it would appear that approximately 1% of the dredged sediment could be lost to the River. Based on a 90 day dredging period, this could introduce up to four times the present HCB flux from the site during the time of the dredging. It is expected that capping can be carried out with only a fraction of this loss.

Conclusions and recommendations

Both the modeling and biological components of this study concluded that toxicological stress in the St. Clair River was confined to the sediment. This conclusion is supported by other independent studies on invertebrate communities that indicate that chemicals bound to sediment are the primary source of exposure in the St. Clair River ecosystem.

It is not known which specific contaminants are the cause of the stress due to the complex mixture of the chemicals in the sediment, but there is good coherence between the levels of HCB and toxicological stress measured in the in vitro assays. Although such a coherence is not a proof that HCB is the primary cause of the toxicological stress, it does support the use of HCB as a model contaminant. HCB, even if not the direct cause of toxicity, definitely shares common physical/chemical properties with the chemical(s) inducing the observed stress (e.g., persistent, hydrophobic, AHH inducer and potentially bioaccumulative). Thus predictions of the model, which are based on the physical/chemical properties of HCB, will accurately reflect the behavior of the chemical(s) of concern.

Essentially, the model predicts that sediment-bound chemicals will be transported downstream and will accumulate in the wetlands of the Walpole Delta. This accumulation is evident in the data presented in that the sediment in Chenal Ecarte was exceeded in toxicological stress only by those being considered for remediation (i.e., Study Area #1). It is beyond the scope of this project to predict the effects of this accumulation of chemicals in the Delta, but previous studies have confirmed the exposure of fish (Hebert and Haffner 1991) and wildlife (Hebert and Haffner 1990) populations of the Delta to HCB and related chemicals (pentachlorobenzene, octachlorostyrene). Furthermore, Hudson and Ciborowski (1996) observed considerably elevated levels of deformities in midge fly larvae (*Chironomus, Phaenopsectra*) at the same site used in this study.

The following recommendations are based on the model predictions that currently 15 g/d of HCB are being exported from the site of concern, and that this loading will only decrease by 25% by the year 2010 if no remedial actions are implemented. Such an option will not directly affect drinking water quality in the system, but disturbance of the contaminated site by shipping, accidents, and rare events can cause a significant pulse of chemicals to be brought up into the water column. Most chemicals will be deposited in the Delta and a significant quantity will become incorporated into the food chain of the wetlands.

Within the Study Area # 1, the geo-statistically interpolated TSQS values produced three zones of impairment: highest, moderate, and lowest. Based on the results of the component studies, with respect to the Study Area # 1, the following management options are recommended:

1. The principle of virtual elimination should be applied to discharge of toxic chemicals from the Cole Drain.
2. The highest impaired areas should be capped or dredged using the technology demonstrated by Dow Chemical in the 1996 environmental dredging.

The recommended actions will have the following benefits:

- These actions would essentially meet all of the short and long-term sediment, water, and biota "yardsticks" of the Remedial Action Plan (RAP) and would represent a major step towards removing this site as an Area of Concern. Contaminated sediment directly or indirectly contributes to 5 of 9 beneficial use impairments (MOEE 1995).
- This remediation would yield economic and social benefits such as public confidence in their water supply and development opportunities.
- These actions should accelerate the recovery of the Delta, so that fish advisories for the St. Clair System can eventually be lifted or relaxed. In the absence of remedial work, contaminants such as mercury and HCB will continue to be exported from the site and could be biologically available in the Delta region for the foreseeable future.

- These actions would lower the risk of a serious accidental resuspension of a large amount of chemicals as a result of such events as the propeller wash from an errant ship, a ship going aground, or an extreme natural event such as a large ice jam or anchor ice condition.
- These actions would further strengthen goodwill between the chemical industries at Sarnia and the downriver communities.
- In addition, this site could become the model for other RAPs to follow (particularly on the Connecting Channels). For example, if the Trenton Channel in the Detroit River RAP was remediated to the level recommended in this report, a major environmental hazard in the Great Lakes would be eliminated with significant benefits to the Western Basin of Lake Erie. By the same token, if the St. Clair River is not remediated, it could be used as precedence for inaction in other seriously contaminated sites.

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APPENDIX 16

REPORT FROM BREAKOUT GROUP A

Brief summary of breakout group A

Breakout Group A was facilitated by Gail Krantzberg (MOE) and John Hartig (IJC).

Breakout Group A defined and discussed the critical data elements that should be considered within a framework, addressed the various decision-making tools, examined the role of these decision-making tools in the restoration of beneficial uses, and proposed an "Integrated Framework" for sediment management decisions.

The goal for each of the Breakout Groups was to provide advice on use of data interpretation tools used to make sediment management decisions.

Data elements and conceptual decision-making rules

The first point to be addressed was the problem with decision-making rules in regard to the exact point where we see enough scientific evidence to say "take action". Although there may be similar data at two sites, decisions to act may be for entirely different reasons. So the question was posed: Do we use the same decision-making method at every site, or should the method be more site-specific? There was an agreement throughout the Group that there should be consistent data interpretation rules and protocols applied to all Areas of Concern.

Then the following question was asked: Does a certain result of a protocol lead to the decision to act or not act? A result of a protocol doesn't necessarily determine the action, a combination of tests do. Additional knowledge is necessary. For example, in regard to research needs, ecologically defined points of departure from reference conditions needs to be defined using the direction of the trajectory with respect to distance from the reference condition and with respect to time.

Ways of interpreting data became the next focus. It was stated that when human health is the issue, the decisions tend to be more standard-driven, whereas when the benthic community is the issue, the decisions tend to be more reference-driven. Human health standards might override the benthic community data. Other ways to evaluate the benthic community besides the reference approach include bioassessment, abundance, and diversity. There is no one single way to interpret the data and apply it to all sites.

The next point made was that reference conditions can be used to interpret benthic community and toxicity test data. There is a need for multiple reference sites. The scales will be different when you test at different sites. Selecting reference sites requires examination of the species at hand. A reference site data base needs selection of common protocols. For site-specific conditions, there is a need for an historical control reference site. However, how do you pick the control site, and if in the lab you pass the first site specific control, is there a need to continue?

In regard to the benthic community, bioaccumulation and biomagnification were discussed. In terms of causality, bioaccumulation can be used to interpret observed toxicity, exposure duration, pathways, tumors and deformities, and degree of uptake. In terms of bioaccumulation and biomagnification, we need site specificity for determining remediation. We need to measure changes in the function of the benthos vs. structure.

Bioaccumulation and biomagnification were also discussed as important routes of exposure by which contaminants in the sediment can reach fish and fish-eating birds and mammals, including humans. Contaminants like PCBs can be present at concentrations in sediment which are not toxic to benthic invertebrates, yet can result in fish consumption advisories for humans and impaired reproduction in fish-eating wildlife like mink and bald eagles.

The stability of the area of contaminated sediment was also discussed as a possible criterion by which remediation extent and urgency might be evaluated. A decision might be made to remediate an area despite there being no current toxicity to benthic invertebrates in the laboratory, no change in community structure from reference areas, and no evidence of current exposure to higher trophic levels. For example, a subsurface deposit of contaminants may be at high risk of physical disturbance, which would be expected to result in a change in bioavailability and an increase in the difficulty and expense of later remediation.

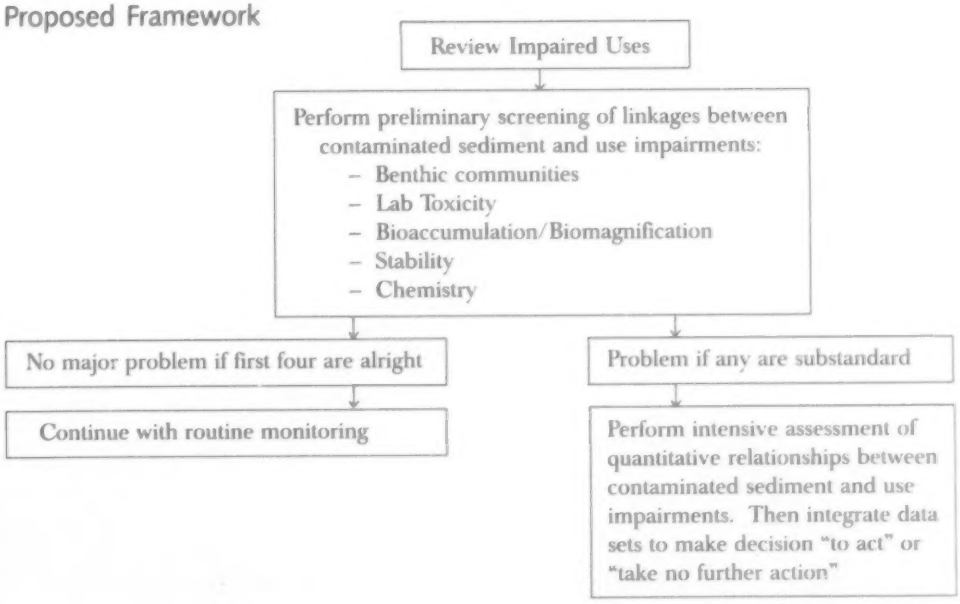
As a result of the points made thus far, the following elements were chosen to be critical in carrying out a proposed Framework: benthos community structure, laboratory toxicity, bioaccumulation and biomagnification, stability, and sediment chemistry. Bioaccumulation and biomagnification includes estimates of tissue concentrations in both invertebrates and vertebrates in the rest of the food web. Stability includes fate and transport, the potential for mobility with disturbance over long time periods, and the bioavailability over a range of sediment, sediment porewater, organismal micro-environment and over-lying water chemistry (e.g., pH, redox, hardness).

The next point made was the difficulty in quantifying the relationship between contaminated sediment and beneficial uses. We need to begin by examining use impairments and their link to sediment quality. The following screen was outlined to determine if and when remediation is necessary. You must examine the following:

- Benthic Community
- Lab Toxicity
- Bioaccumulation/Biomagnification
- Stability
- Chemistry

You cannot base a "no action" decision on any one element solely. Generally, you base a decision on the integration of these five elements through interpreting data sets and attempting to determine causality and linkages to beneficial uses.

Proposed Framework


Review Impaired Uses
Perform preliminary screening of linkages between contaminated sediment and use impairments:
– Benthic communities
– Lab Toxicity
– Bioaccumulation/Biomagnification
– Stability
– Chemistry
No major problem if first four are alright
Continue with routine monitoring
Problem if any are substandard
Perform intensive assessment of quantitative relationships between contaminated sediment and use impairments. Then integrate data sets to make decision "to act" or "take no further action"

APPENDIX 17

REPORT FROM BREAKOUT GROUP B

Brief summary of breakout group B

Breakout Group B was facilitated by Marcia Damato (U.S. EPA) and David Cowgill (U.S. EPA).

Breakout Group B discussed the circumstances under which one would utilize the "Weight of Evidence" approach to sediment assessment vs. a "Tiered Approach". Whichever framework is selected should be consistent at a scientific level in its approach and information. It should also accommodate any size and scope of a project. The group acknowledged that there is considerable frustration associated with dealing with contaminated sediment because of the slow progress of remediation.

Weight of evidence approach vs. tiered approach

The group discussed the "Tiered Approach" and determined that it is useful for smaller, less complex sites such as Collingwood Harbour, but is not as applicable in an area such as the Detroit River Area of Concern. A "Weight of Evidence" approach should often be used on larger, more complex projects. The group noted that chemistry can't be disconnected from the biology for Superfund Sites. For example, in the Great Lakes, nearly all Superfund Projects use the "Weight of Evidence" approach. Sometimes the "Weight of Evidence" approach and the "Tiered Approach" result in the same decisions being made. The group noted that when working with industry in a partnering/cooperative forum where their involvement is voluntary, a reasonable approach is to use a limited amount of data that has been accepted by all parties. The group agreed that the cost of cleanup is a factor in both approaches.

Weight of Evidence	Tiered
Larger Scale	Smaller Scale
Complex	More simple
Non-voluntary	Voluntary parties
Multiple Sources	Single Source

After the science is accepted in defining a problem, then the next steps must be determined. There must be consistency in data interpretation. The group acknowledged the influence of social-political pressures on contaminated sediment problems. The group agreed that the approach should be science-based and the social-political influence should be limited. Science should be used to achieve a comfort level for the decision being made and social-political considerations should be considered later in the process.

Data elements and assessment

The group then discussed some of the important information that should be incorporated into a consistent framework. The following data elements were identified which will help determine the extent of risk from sediment contamination. Is there a risk to:

- Aquatic Life?
  (i.e., toxicity, bioaccumulation, chemistry, and impaired benthic community)
- Wildlife?
  (i.e., bioaccumulation, biomagnification)
- Human Health?
  (i.e., exposure, biomagnification, fate, and transport)

The logic of what entails a complete assessment was discussed next. The group discussed the importance of making a determination of: whether sources of contamination have been controlled; the extent of risk to aquatic, wildlife, and human receptors; whether sediment deposits will move over time; and being able to predict when the system will recover (using models to predict when fish consumption advisories will no longer be needed under various remedial options such as dredging, capping, and natural recovery) so that all 14 beneficial uses have been restored. The following logical steps were identified:

1. Risk Assessment (aquatic, wildlife, and human risk)
2. Benefits Forecasting:

Purpose- Demonstrate benefits and restoration of beneficial uses; public, private, governments

Method- Sources, transport, fate, effects (i.e. mass balance models)

Procedure- Perform the following checks:

What are the sources? Are they controlled?

Is it feasible to remediate?

Where to remediate? How much?

What will happen if:

No further action is taken (natural recovery)?

A catastrophic event occurs?

Other selected scenarios occur?

We achieve the maximum remediation bound (i.e. if we take out everything, how much good will it do)?

Endpoints- sediment contaminant concentration, fish concentrations (over time), toxicity benthic community

Engineering issues- disposal, removal methods, risk to wildlife, risk to habitat

Summary and conclusions

Finally, the group attempted to summarize what had been discussed, recognizing that a number of important factors had been identified. One concept that was posed was that if one were asked to perform a peer review of someone else's sediment management decision, what criteria would you use to evaluate the quality of the decision? This appears to be a concept that could be of use in ensuring that all of the important factors identified above, and aggregated during the plenary session, are given thorough consideration for all Great Lakes sediment projects, regardless of the organization that is responsible for the project and the particular program making the decision.

The group discussed the importance of a Great Lakes protocol that would address sampling, QA/QC, assessment, and data interpretation. The group recommended that there may be a need for "bench marking" (baseline from which we make decisions) among the two provinces, eight states, and two federal governments for three categories of data elements and source control, natural recovery, etc. It was noted that the Great Lakes Water Quality Initiative in the United States took eight years of coordination, consensus building, and administrative rule-making to develop consistent water quality standards for the Great Lakes. Any such protocol would likely be very resource intensive and time-consuming. Therefore, a first step could be to "bench mark", or document, the existing decision-making frameworks now being used. It was noted that the United States Environmental Protection Agency published a document in 1990 entitled "Managing Contaminated Sediment: EPA Decision-Making Processes".

APPENDIX 18

SEDIMENT PRIORITY ACTION COMMITTEE MEMBERSHIP

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